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Geochemical and Geochronological Constraints on the Suture Location Between the North and South China Blocks in the Dabie Orogen, Central China

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Abstract. The Dabie orogen is a collision zone between the North China block (NCB) and South China block (SCB), and a famous ultrahigh pressure metamorphic belt in the world. Location of the suture between the NCB and SCB in the Dabie orogen is still a controversial issue. We identify that the metabasaltic volcanic rocks from the Dingyuan Formation of the Beihuaiyang zone located in the northernmost Dabie orogen have typical geochemical feature of island arc basalt, e.g. negative Nb, Ti and P anomalies in trace elemental spidergram and high LREE, Ba and Pb abundance. Their Sm-Nd and Rb-Sr whole-rock isochron ages are 446±23Ma and 444±31Ma, respectively. These ages are consistent with the age of the island arc volcanics in the North Qinling belt that was the south active continental margin of the NCB in the Paleozoic. These data, together with the similarity in metamorphic history between the Dingyuan Formation and North Qinling belt, suggest that the Dingyuan formation is a Paleozoic magmatic arc on the south margin of the NCB. The Nd isotopic model ages of the Devonian metasediments from the Foziling flysch formation of the Beihuaiyang zone (T_{DM} = 1.7 to 1.9Ga) are younger than those of the northern Paleozoic sediment cover of the SCB (T_{DM} = 1.9 to 2.1Ga). It suggests that more Phanerozoic volcanic material, which could be derived from the active continental margin of the NCB, was involved into the flysch formation. The Huwan tectonic melange zone located to the south of the Dingyuan Formation was formed in Triassic. The eclogites involved in this melange zone were formed in the Carboniferous (301 ± 13 Ma). Their protoliths could be middle Paleozoic oceanic crust or late Proterozoic to early Paleozoic island arc basalt. All these data together with the recent discovery of the Triassic eclogites in the Northern Dabie Zone place important constraints on the suture location between the NCB and SCB. It should follow the Huwan tectonic melange zone in the west and the boundary between the Northern Dabie zone and the Beihuaiyang zone in the east.

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1 Introduction

The E-W trending Qinling-Dabie-Sulu orogenic belt was formed during the collision between the North China Block (NCB) and South China (or Yangtze) Block (SCB). Geologically, the belt is truncated and separated by two major geological elements — the Nanyang basin and the Tanlu fault (Fig. 1). The belt therefore can be subdivided into three major section — the Qinling orogen (west), the Dabie orogen (middle) and the Sulu terrane (east) (Fig. 1). It is generally believed that the Sulu terrane is the eastern extension of the Dabie orogen and was displaced ~ 500 km by the left-lateral movement of the Tanlu fault. Various types of ultrahigh-pressure metamorphic (UHPM) rocks including coesite- and diamond-bearing eclogite are exposed in the Dabie-Sulu orogen (Okay et al., 1989; Wang et al., 1989, 1991; Xu et al., 1992 a; Zhang and Liou, 1994; Cong et al., 1995). It is generally agreed that the Dabie-Sulu UHPM belt may be the largest one on the Earth surface. Investigation of the tectonic framework and evolution of this UHPM belt is of critical importance in understanding the process of continental collision that produced the extreme metamorphic conditions. Location of the suture between the NCB and SCB in the Dabie Mountains is one of the major issues in this investigation.

It is, in general, accepted that the Dabie orogen can be subdivided into five metamorphic zones from north to south (Figs. 1 and 2): (1) Beihuaiyang greenschist-amphibolite facies zone, (2) Huwan cold eclogite melange zone which is limited in the western part of the Dabie orogen, (3) Northern Dabie complex zone, (4) Southern Dabie UHPM zone which contains coesite-bearing eclogite, (5) Hong'an-Susong high-pressure metamorphic (HPM) zone which contains "cold" eclogite and blueschist. Abundant geochronological studies of the UHPM rocks and blueschist from zones 4 and 5 show that this high-pressure (HP) metamorphic belt was formed in the Triassic (Li et al., 1989, 1993, 1994a, 1999a, 2000; Ames et al., 1993, 1996; Eide et al., 1994; Hacker and Wang, 1995; Chavagnac and Jahn, 1996; Rowley et al., 1997; Hacker et al., 1998). Many of

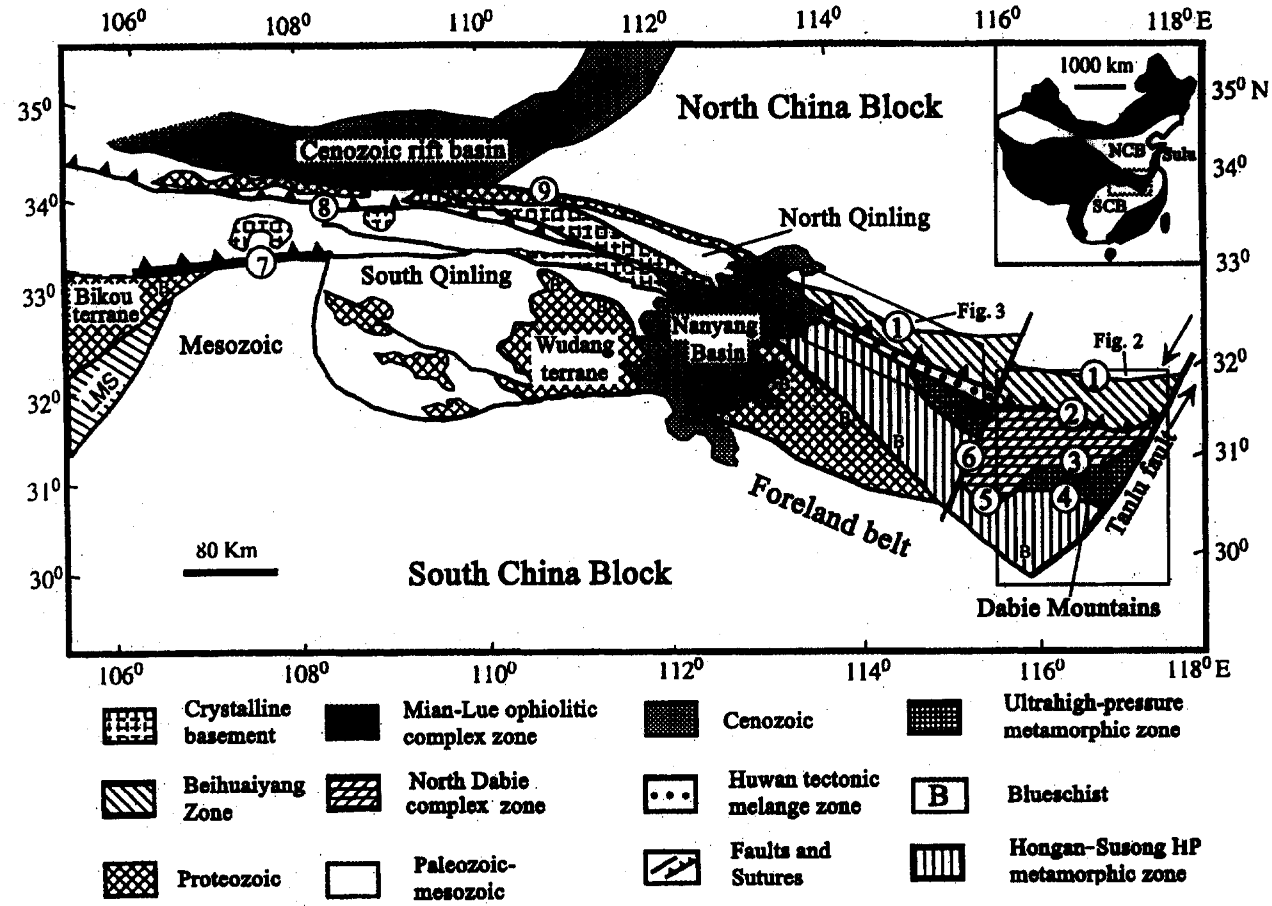

Fig. 1. Geological sketch map of the Qinling-Dabie orogenic belt. (1) Xinyang-Shucheng fault; (2) Tongbai-Mozitan fault; (3) Wuhe-Shuihou fault; (4) Mamiao-Taihu fault; (5) Xishui-Yingshan ductile shear zone; (6) Shang-Ma fault; (7) Mian-Lue fault zone; (8) Shang-Dan fault; (9) Luanchuan fault.

researchers believe that the zones 4 and 5 are subducted continental crust of the SCB, whereas the tectonic settings of the zones 1, 2 and 3 are still controversial. For example, Okay and Sengör (1993) suggest that the suture between the NCB and SCB is located to the North of zone 1, and zone 1 probably represents the passive continental margin of the SCB. The similar conclusion has been reached by Hacker et al. (1998) from U-Pb and Ar-Ar datings together with eclogite distribution in the Dabie orogen and by Zhou and Zheng (2000) from an investigation of low-grade metamorphic rocks in the Dabie-Sulu orogen. Liu and Hao (1989), Xu et al. (1992b) and Hacker et al. (1995) argued that the boundary between the zones 1 and 3 represents a suture between the SCB and NCB, and zone 1 is a forearc flysch formation. Cong et al. (1994) propose that zone 3 could be an island arc near the NCB, thus the suture between the NCB and SCB should be located on the south boundary of zone 3, and zone 1 should be a back-arc basin formation. Obviously, the tectonic setting of the zones 1, 2 and 3 are critical to understand the location of the suture between the NCB and SCB and tectonic evolution of the Dabie orogen. The absence of Paleozoic magmatic arc in zones 1 and 2 and a lack of Triassic eclogite in zone 3 were the major difficulties in understanding of their tectonic settings. New geochemical, isotopic and chronological data are presented in this paper, which place close constraints on the tectonic setting of the zones 1, 2 and 3.

2 Geological framework of the Qinling orogen

The geologic framework and tectonic evolution of the Qinling orogen has been well investigated (e.g. Zhang et al., 1995; Meng and Zhang, 1999, 2000). In order to understand the tectonics of the Dabie orogen better, we will compare the geological units in the Dabie orogen with those in the Qinling orogen in the following section. Hence, before discussing the tectonics of the Dabie orogen, we briefly introduce the geological background of the Qinling orogen first.

The Qinling orogen is a multi-system orogenic belt with two mountain chains. It is divided into two parts, that is the North Qinling and South Qinling belts, along the Shangdan fault (Fig. 1). The North Qinling belt is regarded as a

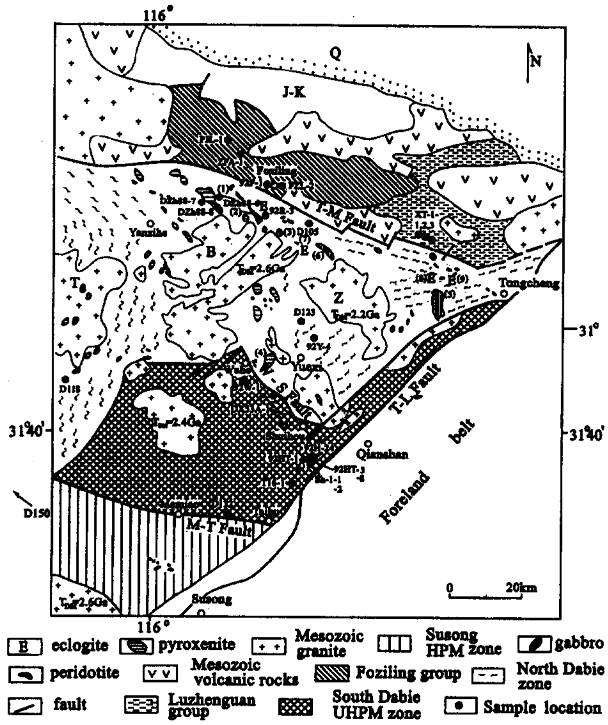

Fig. 2. Geological sketch map showing distribution of mafic-ulrtamafic rocks and eclogites in the North Dabie zone and locations of the samples in Table 3 in eastern Dabie orogen. Zhujiapu pyroxenite; (2) Raobazhai peridotite, garnet pyroxenite or eclogite; (3) Renjiawan pyroxenite; (4) Zhongguan pyroxenite; (5) Jiaoyan gabbro; (6) Xiaohekou gabbro; (7) Huangweihe eclogite; (8) Baizhangyan eclogite; (9) Huazhuang eclogite. T-M Fault: Tongbai-Mozitan fault; W-S Fault: Wuhe-Shuihou fault; M-T Fault: Mamiao-Taihu fault; T-L Fault: Tan-Lu fault.

middle Paleozoic orogen (Mattauer et al., 1995) with widespread Paleozoic island-arc type magmatism represented by metavolcanic rocks in the Danfeng and Erlangping Groups (Sun et al., 1987; Li et al., 1989; Lerch et al., 1995) and metamorphism (Sun et al., 1996 a, b; Zhai et al., 1998). The South Qinling belt is regarded as a Late Paleozoic to Early Mesozoic orogen with abundant Triassic granites and metamorphism (e.g. Mattauer et al., 1985; Xu et al., 1991; Li and Sun, 1996). It is, in general, accepted that the North Qinling belt evolved into an active margin of the NCB during the period from Ordovician to Silurian because of the northward subduction of the Proto-Tethyan Qinling ocean (e.g. Zhang et al., 1995; Li and Sun, 1996; Meng and Zhang, 2000). The Danfeng magmatic arc evolved along its south margin is composed of island-arc type matavolcanics (Danfeng Group) with a Rb-Sr whole rock isochron age of 447.8±41.5Ma (Sun et al., 1987) and mafic intrusions (norite-gabbros) with a Sm-Nd mineral isochron age of 402.6±17.4Ma (Li et al., 1989). Radiolarians in the cherts interlayered with the basalts in Danfeng Group also indicate the ages of Ordovician to Silurian (Cui et al., 1995). Geochronological studies show that this island-arc type magmatism was terminated in the Devonian (Lerch et al., 1995; Li and Sun, 1996).

Recent studies suggest that the South Qinling belt was a microcontinent between the NCB and SCB during the Middle Paleozoic time, which was separated from the SCB by Mian-Lue ophiolite complex zone (① in Fig. 1) (Zhang et al., 1995; Yin and Huang, 1995). Radiolarians in the cherts interlayered with the basalts in Mian-Lue ophiolite complex indicate the age of Carboniferous. It is argued that the initial collision between the NCB (including the North Qinling belt) and South Qinling microcontinent took place in Middle Paleozoic along the Shangdan suture(⑧ in Fig. 1) (Meng and Zhang, 2000). This idea is supported by the termination of island-arc type magmatism in the North Qinling belt in the Devonian (Lerch et al., 1995; Li and Sun, 1996). The Devonian metaclastic flysch formation (Liuling Group) developed along the Shangdan suture, which received the detritus from both the North Qinling and South Qinling belts (Yu and Meng, 1995), suggests that the ocean between the North Qinling and South Qinling belts was closed in the Devonian. A $^{40}Ar/^{39}Ar$ age of 314±6Ma for biotite from the left-lateral strike slip fault along the Shangdan suture also indicates that this collision should be occurred before 314Ma (Mattauer et al., 1985). On the other hand, the Sm-Nd and Rb-Sr metamorphic ages of 242±21Ma and 221±13Ma for the metabasalts from the Mian-Lue ophiolite complex suggest that the Mian-Lue ocean could be closed in Triassic, resulting in the collision between the SCB and South Qinling microcontinent (Li et al., 1996). This idea is supported by the Triassic syncollisional granites (with U-Pb zircon ages of 206 to 220Ma) broadly developed to the north of the Mian-Lue suture and south of the Shangdan suture (Li and Sun, 1996; Sun et al., 2000). The seismic reflection profiling in eastern Qinling shows that the South Qinling belt as a nappe overlies on the subducted continental crust of the SCB after the collision (Yuan et al., 1994).

Since the Dabie orogen is the eastern extension of the Qinling orogen, they should have the similar history of tectonic evolution. However, because the most of the upper crust over the subducted continental crust of the SCB in the Dabie orogen has been removed out by erosion, some geological records in the Qinling orogen, such as ophiolite, micro-continent, and the Triassic syncollisional granite, may not be observed in the Dabie orogen. Thus care should be taken when comparing the two orogens.

3 Beihuaiyang greenschist- to amphibolite-facies zone: Geochemical constraints

This zone is located on the northernmost part of the Dabie orogen and bounded by a WNW-ESE trending, north dipping Tongbai-Mozitan fault on the south (② in Fig. 1) (Xu et al., 1992b; Dong et al., 1993; Okay and Sengör, 1993) and the south-dipping Xinyang-Shucheng fault on the north (① in Fig. 1) (Xu et al., 1992b). It suffered metamorphism of greenschist- to amphibolite-facies and intensively ductile shear deformation with many mylonite occurrences. It may be subdivided into two units (Figs. 2 and 3). The lower unit is composed of the Guishan complex of the Xinyang Group and the Dingyuan formation in the west (see Fig. 3) and Luzhenguan Group in the east (Fig. 2). It is composed of various gneisses, amphibolite, garnet mica schist, chlorite or chlorite albite schist, marble and quartzite; their protoliths were suggested to be keratophyre, andesitic tuff and basalts. Protoliths of the K-feldspar gneiss and mica-schist could be sandstone and pelite (Xu and Hao, 1988; Xu et al., 1992b).

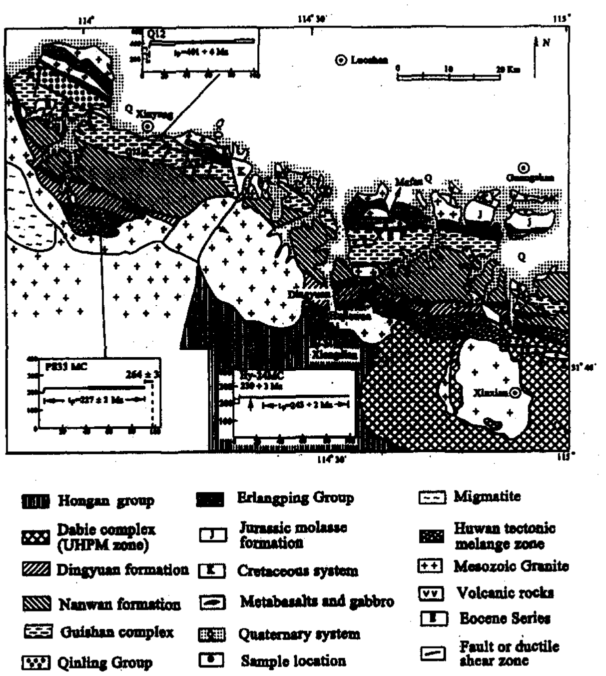

Fig. 3. Geological map showing relationship between the Guishan complex, Nanwan formation, Dingyuan formation and Huwan tectonic melange zone in the Beihuaiyang zone in western Dabie orogen. XSF: Xinyang-Shucheng fault. The $^{40}Ar/^{39}Ar$ data are from Niu et al. (1994) and Ye et al. (1993).

The upper unit includes the Nanwan formation of the Xinyang Group in the west (Fig. 3) and the Foziling Group in the east (Fig. 2). It is separated from the lower unit by ductile shear zone or fault (Fig. 3). This unit is a metaclastic flysch formation with rhythmic layers of slate, phyllite, mica quartz schist and quartzite and the metamorphic grade greenschist facies (Xu and Hao, 1988; Chen and Sang, 1995). Devonian fossils in this unit (Gao et al., 1988) suggest a Devonian deposition for the Foziling Group and Nanwan formation.

3.1 Geochronology and geochemistry of the lower unit

Ye et al. (1993) reported a U-Pb zircon age of 392±25Ma on acidic metavolcanics from the upper formation of the Guishan complex. It is the lower intercept of disconcordia line. We interpret this age as metamorphic age of the acidic metavolcanics. More dating results support our interpretation. For example, an amphibole sample separated from a garnet-amphibolite (Q12) in the Guishan complex yields a perfect $^{40}Ar/^{39}Ar$ plateau age of 401±4Ma (Fig. 3 of Niu et al., 1994), which indicates the metamorphic time of the lower unit. In addition, the Rb-Sr whole-rock isochron of tuff from the Dingyuan area yields an age of 391±13Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7079 (Ye et al., 1993). This age might also indicate the time of metamorphism. These ages of the lower unit in the Beihuaiyang zone are consistent with the metamorphic age of the North Qinling belt, a Paleozoic island arc near the NCB (Zhang et al., 1995). For example, the hornblende and biotite from the metamorphic rocks in the North Qinling belt yield $^{40}Ar/^{39}Ar$ ages of 434 to 404Ma and 348 to 327Ma, respectively (Sun et al., 1996a; Zhai et al., 1998; Mattauer et al., 1985). Rb-Sr whole-rock isochron as well as Sm-Nd and Rb-Sr mineral (hornblende + plagioclase + whole rock) isochrons of amphibolites from the North Qinling belt give ages of 402 to 414Ma (Sun et al., 1996 a, b). All of these geochronological data suggest that the lower unit in the Beihuaiyang zone and the North Qinling belt experienced the same metamorphism at around 400Ma. However, the formation age and tectonic setting of the lower unit are still unknown. In order to solve these questions, we have studied the geochemistry and geochronology of metabasalts from the Dingyuan formation.

Four metabasaltic and basaltic-andesite samples (95HN-S-1, -3, -5 and -6) and 2 acidic samples (95HN-S-2 and -4) were collected from the Dingyuan formation at one stone pit in Dingyuan (Fig. 3). The rocks in this stone pit are almost metabasalts, while a few acidic blobs with the diameters of 10 to 20cm have been observed. Two foliations can be recognized in both basaltic and acidic rocks, suggesting that the basaltic and acidic rocks have the same deformation history. Petrography of these rocks shows typical volcanic porphyritic structure. The phenocrysts in the metabasalts are composed of augite, plagioclase and minor opaque minerals. Sample 95HN-S-6 contains more abundant opaque minerals (~10 %) which severely affect its major and trace element contents. Muscovite is developed along the foliations in all basaltic samples. The matrix is mainly composed of pyroxene, plagioclase and amphibole, but most of them are partly replaced by abundant chlorites or epidote. The metamorphic mineral assemblage of chlorite + epidote + muscovite suggests a high greenschist-facies metamorphism. The phenocrysts in the acidic rock are mostly plagioclase. Its fine grain matrix is composed of quartz, plagioclase and muscovite. Muscovite developed along the foliations, but was folded by the second deformation. The typical volcanic porphyritic structure of the acidic rock and its similar deformation history to the metabasalts suggest that the acidic blobs in metabasalts are not the metamorphically fractional product, but more likely to be magmatically fractional product (deformed acidic dyke in basalt).

Major and trace elements (see Table 1) as well as Sr and Nd isotopes (see Table 2) have been analyzed for these samples. Based on their SiO_2 and (Na_2O + K_2O) contents, the metabasalts in the Dingyuan formation are basically subalkaline basalts excepts the sample 95HN-S-1 which is basaltic andesite. AFM diagram (omitted) shows that these metabasalts belong to calc-alkaline series excepts for the sample 95HN-S-6 that contains abundant opaque metallic minerals, thus more Fe_2O_3 than other samples.

Table 1. Major element (%) and trace element (ppm) compositions of the metavolcanics from the Dingyuan formation*

elements	95 HN-S-1	95 HN-S-2	95 HN-S-3	95 HN-S-4	95 HN-S-5	95 HN-S-6
SiO_2	55.01	75.75	51.86	75.15	48.25	50.41
TiO_2	0.99	0.25	1.23	0.28	1.45	3.71
Al_2O_3	16.60	12.82	16.05	13.37	17.08	12.25
Fe_2O_3	3.90	0.87	3.69	1.12	0.38	7.22
FeO	3.40	0.32	5.52	0.30	10.36	8.34
MnO	0.107	0.011	0.133	0.007	0.153	0.155
MgO	3.96	0.45	6.30	0.58	5.59	4.56
CaO	7.82	0.90	6.03	0.70	8.95	6.84
Na_2O	4.00	5.84	2.87	5.07	1.60	1.06
K_2O	0.99	1.13	1.83	1.90	1.14	0.42
H_2O^+	2.74	0.70	3.72	1.29	4.26	4.35
CO_2	0.06	0.64	0.72	0.01	0.29	0.08
P_2O_5	0.023	0.016	0.088	0.019	0.018	0.033
Total	99.60	99.70	100.04	99.80	99.52	99.43
TFe_2O_3	7.68	1.23	9.82	1.45	11.89	16.49
Ti	4615.40	1184.40	5755.10	1351.20	6416.60	10753.00
Cr	68.52	12.21	116.02	12.37	49.98	40.45
Co	14.61	3.09	30.80	5.39	28.24	37.73
Ni	52.48	32.54	84.85	58.07	107.40	95.97
Cu	14.91	7.05	32.30	9.35	38.46	98.86
Zn	57.99	16.91	95.69	22.03	104.65	110.03
Rb	20.22	23.38	38.36	40.66	24.04	10.30
Sr	979.02	185.26	644.32	137.75	1537.80	940.06
Y	16.08	14.94	18.48	18.31	12.06	50.16
Zr	166.14	192.63	117.95	200.82	43.39	309.92
Nb	8.92	15.42	8.50	14.07	1.95	21.43
Sn	1.35	1.82	1.62	2.25	1.01	1.80
Cs	0.79	0.73	1.07	1.29	0.77	0.86
Ba	642.32	728.56	1025.10	1017.90	604.59	379.94
La	29.28	64.43	32.84	69.36	6.97	37.74
Ce	57.47	119.23	66.81	128.78	17.71	86.06
Pr	7.24	12.52	8.43	12.69	2.74	11.25
Nd	28.97	40.95	32.81	45.38	6.30	50.05
Sm	5.31	5.73	4.97	7.25	4.55	13.10
Eu	2.25	1.54	2.05	1.63	1.91	4.35
Gd	5.36	5.20	5.11	6.48	4.60	16.26
Tb	0.64	0.78	0.77	0.71	0.66	2.28
Dy	4.08	3.75	4.06	4.47	2.87	13.77
Ho	0.93	0.89	1.12	0.88	0.60	2.49
Er	2.34	2.31	2.76	3.09	2.03	8.08
Tm	0.26	0.39	0.56	0.43	0.40	0.83
Yb	2.23	2.91	2.34	2.96	2.69	5.45
Lu	0.24	0.35	0.42	0.26	0.30	0.67
Hf	3.63	7.32	4.83	7.17	1.18	12.03
Ta	1.11	1.75	1.87	2.34	0.58	2.46
Pb	113.87	7.68	15.48	4.31	23.96	23.68
Bi	0.34	0.18	0.20	0.35	0.07	0.20
Th	5.15	15.27	3.40	12.88	1.07	5.84
U	0.92	2.54	0.76	2.10	0.56	1.48
Ba/Nb	72	47.2	120.6	72.3	310	17.7
La/Nb	3.28	4.18	3.86	4.93	3.57	1.76
La/Ce	0.51	0.54	0.49	0.54	0.39	0.44
Th/Nb	0.577	0.990	0.40	0.915	0.548	0.273

* The major element contents were obtained at the Institute of Geophysical and Geochemical Exploratory Techniques, Chinese Academy of Geological Sciences, by X-ray fluorescence analysis except CO_2 and H_2O, which were obtained by nonaqueous titration and gravimetric analysis respectively. Trace element contents were analyzed by ICP-MS at the Institute of Geology, Chinese Academy. The Rb, Sr data obtained by ICP-MS are consistent with the isotope dilution data well (see Table 2). The ICP-MS Nd and Sm data for most samples are basically consistent with the isotope dilution data (Table 2). However, the ICP-MS Nd and Sm abundance of the sample 95HN-S-6 are 3 times higher than the isotope dilution abundance. Those discrepancies between the two procedures may reflect either a lower precision for the ICP-MS analysis or they may reflect the heterogeneity of the sample which contains more abundant opaque minerals. Those discrepancies are not yet resolved, but they do not affect the interpretation of the data presented here.

Table 2. **Sr and Nd isotopic compositions of the metavolcanics from the Dingyuan formation.**

Sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$ ± 2σ	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ ±2σ	$\varepsilon_{Nd}(t)$*
95 HN-S-1	20.78	962.3	0.0628	0.706502± 29	6.178	30.63	0.1220	0.511986 ± 18	-8.5
95 HN-S-2	28.95	185.6	0.4553	0.708886±17	5.369	36.98	0.0879	0.511898 ± 13	-8.2
95 HN-S-3	40.16	646.7	0.1802	0.707225± 28	3.576	14.56	0.1486	0.512085 ± 14	-8.0
95 HN-S-4	45.76	143.9	0.9313	0.711910± 24	6.849	31.15	0.1330	0.512040 ± 16	-8.0
95 HN-S-5	24.64	1541	0.0465	0.706351± 30	3.681	13.37	0.1664	0.512134 ± 17	-8.2
95 HN-S-6	9.327	951.8	0.0285	0.706109± 25	4.598	14.45	0.1925	0.512201 ± 11	-8.3

* The Rb-Sr and Sm-Nd isotope data were obtained at the Isotope Laboratory of the Modern Analysis Center, Nanjing University, following procedures described elsewhere (Li et al., 1994a). The $^{143}Nd/^{144}Nd$ ratios were normalized relative to the value of $^{146}Nd/^{144}Nd$ = 0.7219. Blank for the whole chemical procedure are 50-60 pg for Sm an Nd, 0.1 ng for Rb and 1 ng for Sr. The Nd and Sr isotopic standard values analyzed in this experiment are 0.511864 ± 8 for La Jolla Nd Standard and 0.710241 ± 11 for NBS 987 Sr standard. Ages are calculated using "ISOPLOT" software provided by Dr. K. Ludwig and given with 2σ error. The initial $\varepsilon_{Nd}(t)$ is calculated using t = 446 Ma.

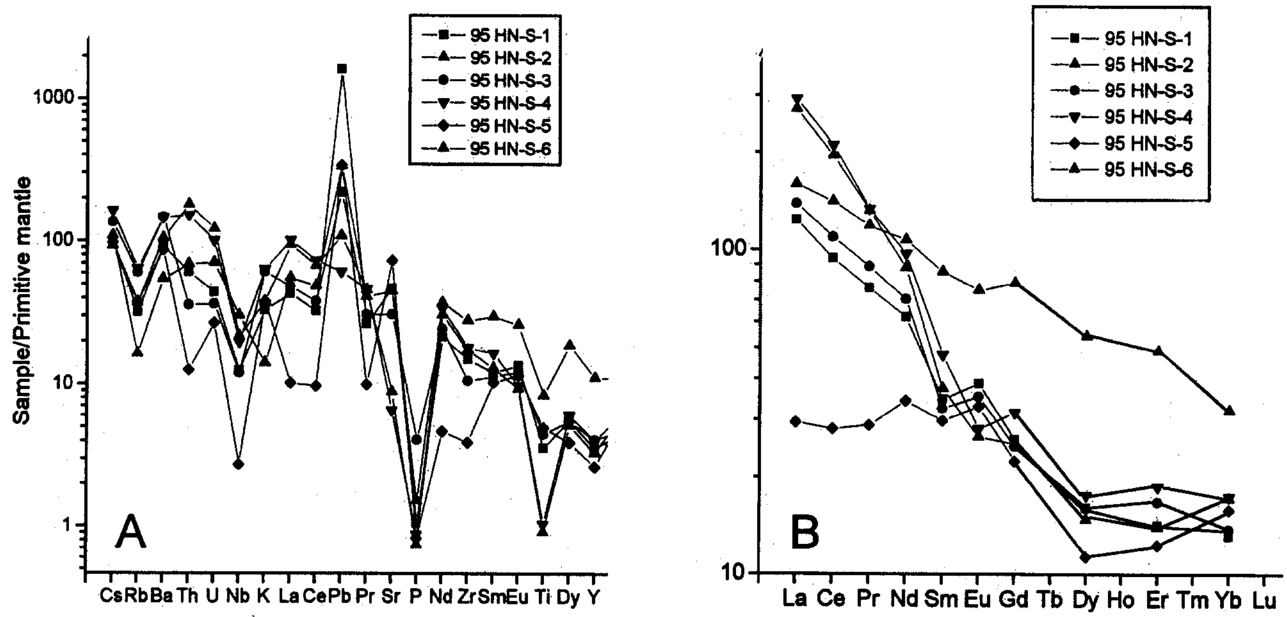

Fig. 4. Element geochemical diagrams for the Dingyuan formation. (A) Trace element primitive mantle normalized spidergram of the metavolcanics from the Dingyuan formation; (B) Chondrite normalized REE patterns of the metavolcanics from the Dingyuan formation. Chondrite values used for normalization are 1.2×(Masuda et al., 1973). Primitive mantle values used are from Sun and McDonough (1989).

The predominant trace elemental characteristics of both metabasalts and acidic rocks in the Dingyuan formation is high Ba, Pb and Sr contents but low Nb, Ti and P contents (Table 1). They display positive Ba, Pb and SR anomalies but negative Nd, Ti and P anomalies in the primitive mantle normalization diagram (Fig. 4 A). These are the typical features of subduction zone related magmas, and very similar to those of the Paleozoic island arc magmatism in the North Qinling belt (Li et al., 1994b; Sun et al., 1995, 1996b). In addition, the high La/Nb, Ba/Nb and Th/Nb ratios of the metabasalts in the Dingyuan formation are also of island arc features (Fig. 5). In addition, since the incompatible elements La, Ce and Nb are immobile during metamorphism (Hart, 1971; Li et al., 1993; Zhao, 1997), the La/Ce and La/Nb ratios of metavolcanics may reflect the ratios of their sources. Table 1 shows that both the basaltic and acidic samples, except the sample 95HN-S-6 which contains more abundant opaque minerals, have similar La/Ce and La/Nb ratios. This suggests that both the basaltic and acidic rocks may be derived from a homogeneous source. The REE chondrite normalization diagram (Fig. 4b) shows that all sample, except the sample 95HN-S-6, have similar HREE flat pattern, but highly fractional LREE patterns including LREE flat pattern

(95HF-S-5) to LREE enriched (95HN-S-1, 3) and highly enriched (acidic rocks) patterns. It may suggest different degrees of partial melting of their mantle source, or high fractionation of the magma.

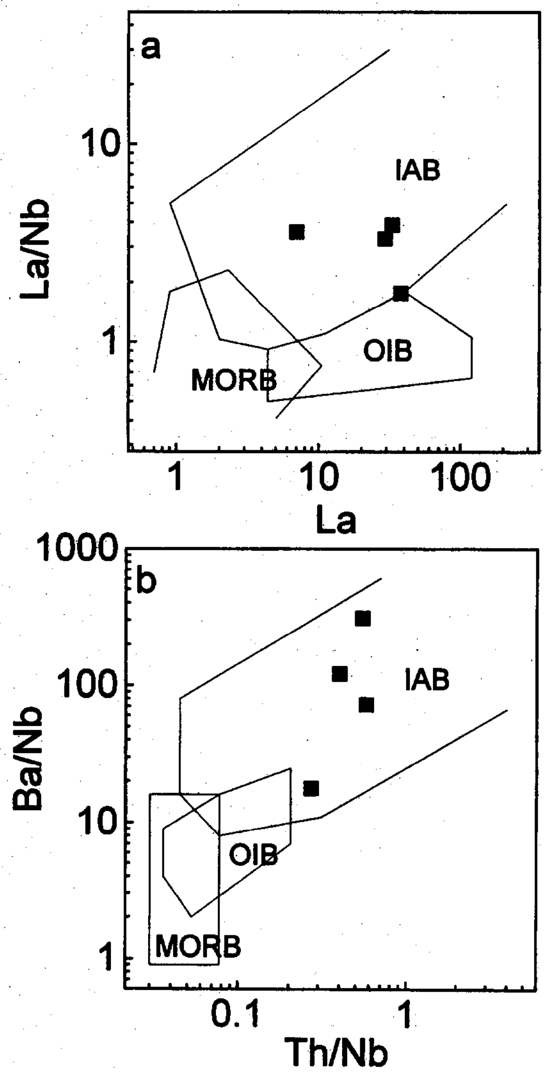

Fig. 5. La/Nb-La and Ba/Nb-Th/Nb plots showing that the metabasalts from the Dingyuan formation are characterized by high La/Nb, Ba/Nb and Th/Nb ratios, falling in the island arc basalt (IAB) field (after Li, 1993).

Figure 6 shows that the Sm-Nd and Rb-Sr whole-rock isochrons yields consistent ages of 446±23Ma and 444±31Ma, respectively. These ages are older than the metamorphic ages of the Dingyuan formation and Guishan complex mentioned above. Therefore, we interpret these ages as the formation age of the Dingyuan metabasaltic rocks. It suggests that island arc magmatism in the Beihuaiyang zone was active in the later Ordovician to early Silurian. The island arc volcanics of the Danfeng Group in the North Qinling belt have the similar geological history. A Rb-Sr whole-rock isochron age of 447.8±41.5 Ma for the metavolcanic rocks in the Danfeng Group (Sun et al., 1987) is consistent with the Rb-Sr and Sm-Nd ages reported in this paper. Therefore, the tectonic setting of the Dingyuan formation could be similar to that of the Danfeng Froup in the North Qinling belt, i.e. it was a Paleozoic magmatic arc on the south margin of the NCB. If it is true, the suture between the NCB and SCB should lie to the south of the Dingyuan formation.

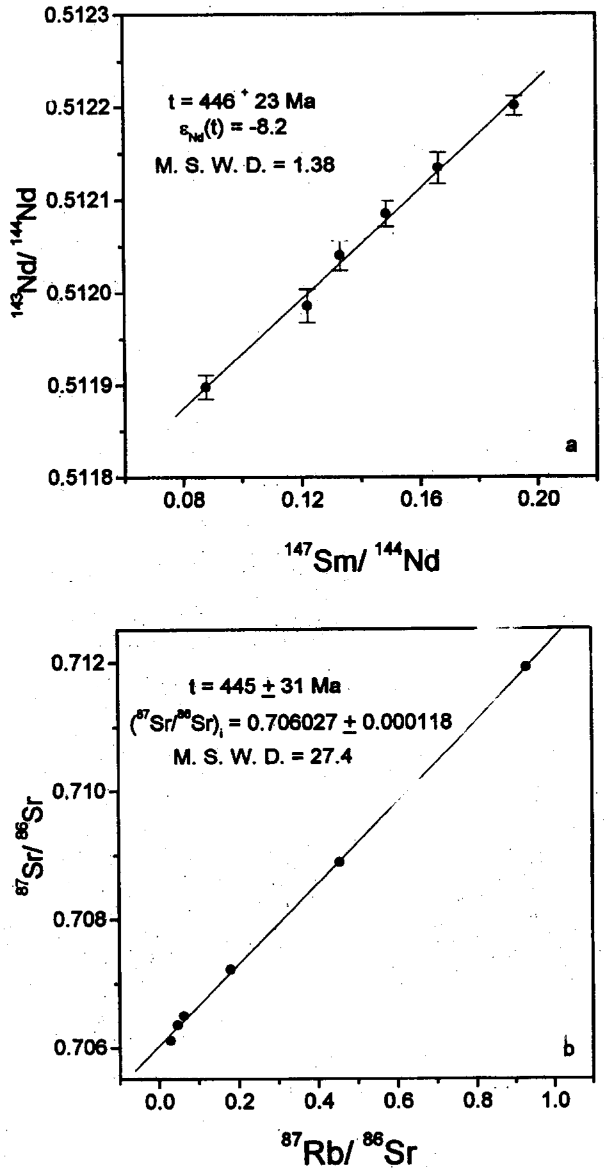

Fig. 6. Rb-Sr and Sm-Nd isochron diagram of the metavolcanics from the Dingyuan formation

3.2 Nd isotopic compositions of flysch formation in the upper unit

The Foziling Group or the Nanwan formation has been considered as the sequences of passive continental margin of the SCB (Okay and Sengör, 1993), the forearc flysch formation of the NCB (Liu and Hao, 1989; Xu et al., 1992b), or the back arc flysch formation of the NCB (Dong

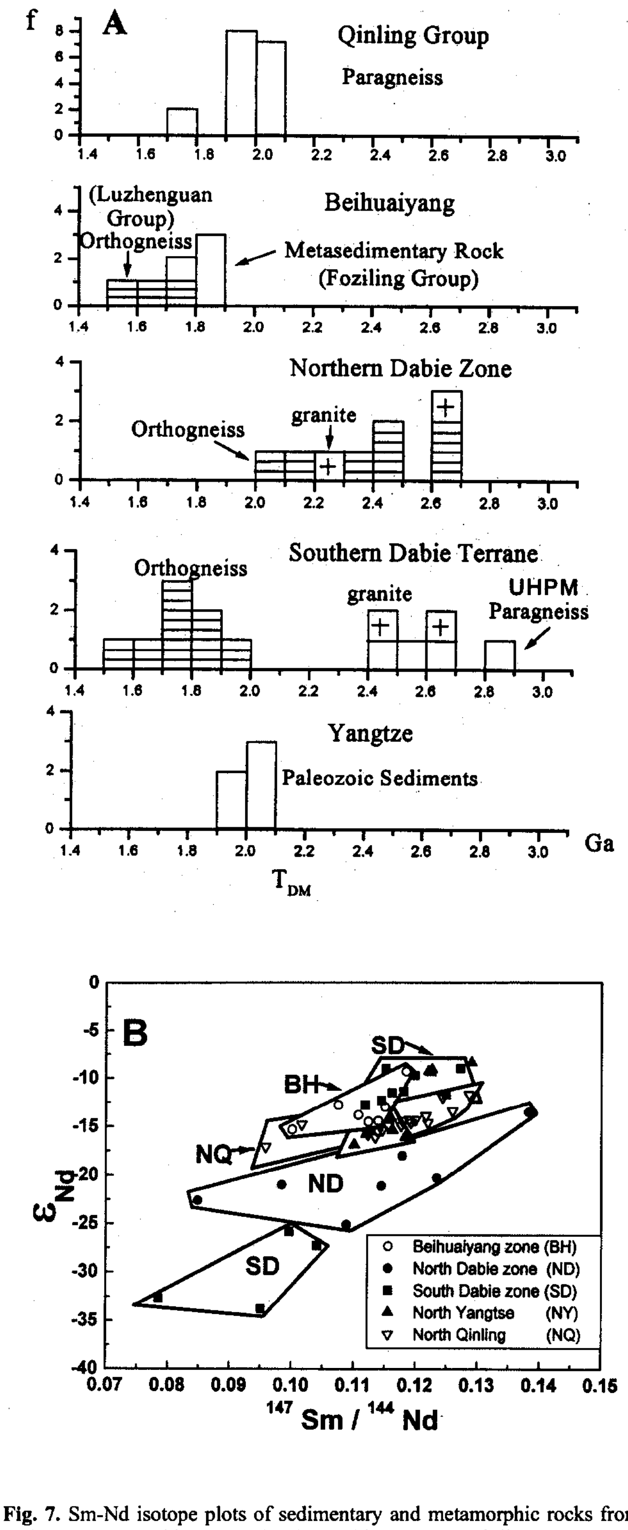

Fig. 7. Sm-Nd isotope plots of sedimentary and metamorphic rocks from various metamorphic zones in the Dabie orogen, Qinling Group and Paleozoic cover of the SCB. (A) Histograms of Nd isotopic model ages (T_{DM}); (B) $\varepsilon_{Nd}(0)$ vs $^{147}Sm/^{144}Nd$ diagram. Note: the UHP metapelite (paragneiss) have significantly higher ε_{Nd} and T_{DM} values than those of granitic gneiss (orthogneiss) in South Dabie zone. The data of granites in the Dabie orogen, data of paragneiss in Qinling Group and Paleozoic sediments in the SCB are from Xie et al., (1996), Z. Zhang et al. (1994) and Chen et al. (1990) respectively. Other data are from Table 3.

et al., 1993; Cong et al., 1994), or a part of accretionary wedge scraped off from the shellow part of the Yangtze plate during the subduction of SCB beneath the NCB (Zhou and Zheng, 2000). Nd isotope model age (T_{DM}) and $\varepsilon_{Nd}(0)$ values at the present time of metasedimentary rocks from the flysch formation (upper unit) in the Beihuaiyang zone can be used to discriminate their tectonicsettings. Sediment with higher volcanic content in active continental margin has lower model ages (T_{DM}) and higher $\varepsilon_{Nd}(0)$ values than those on passive continental margin. Nd isotope model ages of the Paleozoic sedimentary cover on the northeastern part of the SCB near Dabie orogen range from 1.9 Ga to 2.1 Ga (Chen et al., 1990) (Fig. 7A). These sedimentary rocks have low $\varepsilon_{Nd}(0)$ values (−14.1 to −16.9) (Fig. 7B). These data suggest that the Paleozoic sedimentary rocks on the north passive margin of the SCB have old sources and little Phanerozoic volcanic materials. However, the Nd isotope model ages (T_{DM}) of sandstone and metapelite from the Foziling Group range from 1.7 to 1.9Ga (Table 1, Fig. 7A), which are younger than those (1.9 to 2.1Ga) of the Paleozoic sedimentary cover in SCB. Their $\varepsilon_{Nd}(0)$ values (−9.3 to −15.3) (Table 3, Fig. 7B) are higher than those of the Paleozoic sedimentary rocks in SCB. It indicates that more Phanerozoic volcanics were involved into the sedimentary rocks of the Foziling Group. The volcanic material in the Foziling Group could be derived from the active continental margin of the NCB, such as the North Qinling belt or the lower unit in the Beihuaiyang zone. The T_{DM} values of the basement of the North Qinling island arc range from 2.1 to 1.9Ga (Fig. 7A), while the T_{DM} values of island arc volcanic rocks in the North Qinling belt are about 1.0±0.1Ga (Sun et al, 1995, 1996, a, b). Therefore, the T_{DM} values of sediment derived from both the basement and volcanic rocks of the North Qinling belt must be lower than 1.9Ga. In addition, the gneiss from Luzhenguan Group yields lower T_{DM} values of 1.6 to 1.8Ga (Fig. 7A, Table 3). It indicates that the protolith of the gneiss from the Luzhenguan Group could be felsic volcanic rock or tuff that would be expected because of the island arc setting of the lower unit in the Beihuaiyang zone.

3.3 Tectonic evolution of the Beihuaiyang zone

The above geochemical and geochronological data suggest that the tectonic setting of the Beihuaiyang zone in the Dabie orogen is evolutionary. The Beihuaiyang zone is composed of two units. The lower unit of the Beihuaiyang zone including the Guishan complex and the Dingyuan formation, was an island arc or a magmatic arc on the active continental margin in the Ordovician to Silurian. This is supported by the discovery of the Paleozoic magmatic arc of the Dingyuan formation, lower T_{DM} values of the Luzhenguan Group and ~400Ma metamorphic ages of the Guishan complex and Dingyuan formation. These features are consistent with the island arc volcanic rocks in the North Qinling belt which was the south active continental margin of the NCB. Therefore, the lower units of the Beihuaiyang zone could be the active continental margin of the NCB in the Ordovician to Silurian.

Table 3. Nd isotopic compositions and model ages of the gneisses, and metasedimentary rocks from the Dabie Mountains+

Sample	rock type*	Sample location++	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ $\pm 2\sigma_m^{\xi}$	T_{DM}** (Ga)	data source	$\varepsilon_{Nd}(0)$
Beihuaiyang zone									
Foziling group									
92F-1	Sandstone	Foziling	2.626	14.14	0.1123	0.511897 ± 6	1.9	1	-14.5
PJL-1	Muc Qz Sch	Panjialing	5.769	31.52	0.1107	0.511929 ± 12	1.8	1	-13.8
FZL-2	Muc Qz Sch	Foziling	5.066	30.61	0.1001	0.511856 ± 12	1.7	1	-15.3
ZFA-1	Muc Qz Sch	Zhufoan	4.983	26.47	0.1139	0.511900 ± 12	1.9	1	-14.4
Luzhenguan									
XT-1-1	Gn	Xiaotan	10.41	58.57	0.1075	0.511980 ± 16	1.7	1	-12.8
XT-1-2	Gn	Xiaotan	7.784	39.76	0.1184	0.512160 ± 10	1.6	1	-9.3
XT-1-3	Gn	Xiaotan	5.788	30.45	0.1150	0.511971 ± 19	1.8	1	-13.0
NorthDabie zone									
92 R-3	Gn	Raobazhai	18.61	98.41	0.1144	0.511557 ±15	2.4	1	-21.1
DZh-88-6	Bi Gn	Zhujiapu	8.034	41.24	0.1178	0.511716 ± 9	2.3	1	-18.0
DZh-88-7	Gn	Zhujiapu	14.31	70.17	0.1234	0.511596 ± 7	2.6	1	-20.3
DZh-88-8	Bi-Gn-xenolith	Zhujiapu	1.474	10.51	0.0848	0.511480 ± 15	2.0	1	-22.6
92 Y-4	Hb Gn	Yuexi,Fulongzhai	5.911	25.87	0.1382	0.511947 ± 8	2.4	1	-13.5
D 123	Pl. Gn.	Yuexi,Shiguan	9.040	50.25	0.1088	0.511350 ± 6	2.6	3	-25.1
D 105	Hb. Gn.	Mozitan	6.575	40.37	0.09843	0.511560 ± 9	2.1	3	-21.0
South Dabie zone									
DX50A-1	Orthogeneiss	Bixiling	5.312	26.81	0.1198	0.512142 ± 11	1.6	1	-9.7
92 W-1	Orthogneiss	Wumiao	3.257	17.11	0.1151	0.512179 ± 14	1.5	1	-9.0
T16-1	Orthogneiss	Shima	7.334	34.89	0.1272	0.512176 ± 9	1.7	2	-9.0
Sh-1-2	Orthogneiss	Shuanghe	7.835	40.84	0.1161	0.512049 ± 32	1.7	1	-11.5
Sh-1-1	Orthogneiss	Shuanghe	6.635	33.99	0.1180	0.512027 ± 10	1.8	1	-11.4
92HT-3	Metapelite	Shuanghe	6.754	52.02	0.07854	0.510962 ± 8	2.5	1	-32.7
92H-24	Metapelite	Shuanghe	5.533	35.18	0.0951	0.510904 ± 23	2.9	1	-33.8
92HT-8	Metapelite	Shuanghe	6.890	41.84	0.09962	0.511315 ± 32	2.4	1	-25.8
92HT-1	Metapelite	Shuanghe	11.59	71.72	0.1041	0.511210 ± 15	2.7	1	-27.3
D 118	Orthogneiss	Yingshan, Jinpu	7.467	40.36	0.1118	0.511982 ± 7	1.7	3	-12.8
D 132	Orthogneiss	Taihu, Lidu	7.137	37.70	0.1144	0.512005 ± 9	1.8	3	-12.3
D 150	Orthogneiss	Hongan	7.560	36.61	0.1249	0.512038 ± 9	1.9	3	-11.7

+ Samples Sh-1, 92HT-1 were analysed at Max-Planck Institute, Germany; Other data presented in this table were obtained at Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China. Sample locations are shown in Figure 2.
* Muc-Muscovite; Qz-Quartz; Sch-Schist; Gn-Gneiss; Bi-Biotite; Hb-hornblende; P1-plagioclase; Gr-garnet;
++ See Fig.2 for details
ξ Nd isotopic ratios were normalized against $^{146}Nd/^{144}Nd=0.7219$ and adjusted to $^{143}Nd/^{144}Nd = 0.512612$ for the BCR-1 Nd standard.
** Model ages were calculated using the following equation assuming a linear Nd isotopic growth of the depleted mantle reservoir from $\varepsilon_{Nd} = 0$ at 4.56 Ga to $\varepsilon_{Nd} = +10$ at the present. $T_{DM} = 1/\ln\{1 + [(^{143}Nd/^{144}Nd)_{sample} - 0.51315]/[(^{147}Sm/^{144}Nd)_{sample} - 0.2137]\}$, $\lambda = 0.00654Ga^{-1}$.
Data source: 1. This paper; 2. S. Li et al. (1993a); 3. Xie et al. (1996).

The upper unit including the Nanwan formation and the Foziling Group is a Devonian metaclastic flysch formation (Gao et al., 1988). The relative lower T_{DM} values of the sedimentary rocks from the Foziling Group suggests that the flysch formation should be deposited near the active continental margin, such as the lower unit of the Beihuaiyang zone or North Qinling belt. However, a lack of volcanic rocks in the upper unit may suggest the termination of the island arc magamtism in the Beihuaiyang zone in the Devonian. This is supported by the Carboniferous coal series intercalated with marine shales locally overlying the Foziling Group. Extensive conglomerate beds occur along the southern limb of the Carboniferous, and contain various gravels including slate, sandstone, quartzite, black chert, granite and limestone (Ma, 1989). Some gravels (e.g. slate, sandstone) may be derived from the Foziling Group, whereas the Silurian fossils in the limestone pebbles were derived from the early Paleozoic passive continental margin of the SCB or the Gondwana continent (Ma, 1989; Xu et al., 1992b). Based on this observation, some researchers suggest the Middle Paleozoic collision between the NCB and SCB (e.g. Ma, 1989), which contradicts the Triassic age of the UHP metamorphism in the Dabie orogen. In order to reconcile this observation with the Triassic age of the UHPM rocks, a model could be proposed in that there might be a microcontinent (similar to South Qinling?) between the NCB and SCB in the Dabie area in the Middle Paleozoic time, and the ocean between the NCB and the microcontinent was closed at the end of the Devonian. The Beihuaiyang area then became a remnant basin that could receive the detritus from both the northern and southern continental margins. Thus the upper unit of the Beihuaiyang zone could correspond to the Liuling Group, which is a Devonian metaclastic flysch formation in the Qinling area and is located to the south of the North Qinling belt and on the north margin of the South Qinling belt (Zhang et al., 1995; Yu and Meng, 1995). However, the difficulty for this model is that no such a micro-continent has been identified in the Dabie orogen, though it is possible that the microcontinent overlying the subducted continental crust of the SCB in the Dabie area could be removed out by erosion. Another possible model is that the ocean between the NCB and SCB became narrow in the Dabie area in the Devonian, because Paleomagnetic results from China suggest that the collision started earlier in the east than in the west (e.g. Zhao and Coe, 1987). In any case, the upper unit of the Beihuaiyang zone would be developed near the active continental margin of the NCB in the Devonian.

4 Huwan tectonic melange zone: the suture between the NCB and SCB

The Huwan tectonic melange zone is discontinuously exposed to the south of zone 1, in the western part of the Dabie orogen (Figs. 1 and 3). It was previously named the Huwan formation of the "Sujiahe Group" in Chinese literatures. The "Sujiahe Group" was subdivided into two units, the northern metavolcano-clastic rock zone (the Dingyuan formation) and southern eclogite-bearing melange zone (the Huwan formation), which is separated by a north-dipping shear zone (Fig. 3) (Ye et al., 1994). As mentioned above, the northern zone (the Dingyuan formation) in the "Sujiahe Group" and the Guishan complex should be considered as one unit because of their similar lithological characters (Suo et al., 1993) and metamorphic history (this paper). Therefore, the southern zone (Huwan formation) of the "Sujiahe Group" is an independent tectonic melange zone. It is bounded by north dipping shear decollement zones on the north and south (Ye et al., 1994) (Fig. 3), and separates zone 1 from the Tongbai complex and Hongan terrane (Ye et al., 1994; Niu et al., 1994).

The Huwan tectonic melange zone is mainly composed of interleaved blocks and slabs, which are commonly mylonitizated. Eclogite, marble and quartzite lenses are encased in the schist and gneiss which are considered to be an argillitic matrix with metamorphism of greenschist- to amphibolite-facies. The early Paleozoic fossils found in marble block suggest that the carbonates were deposited in the Ordovician (Ye et al., 1994). Abundant geochronological data suggest that the Huwan tectonic melange was formed in the early Triassic. For example, $^{40}Ar/^{39}Ar$ age for white mica from quartz albite muscovite schist and the matrix in the melange zone are 227±2Ma (PS33) (Niu et al., 1994) and 243±2Ma (HY-24) (Ye et al. 1993), respectively (Fig. 3). Two whole rocks (HY62 and HY89) or whole rocks + minerals (muscovite and plagioclase) Rb-Sr isochron ages for mylonites from the shear decollement zone between the melange zone and the Dingyuan formation on the north are 236±11Ma and 225±8Ma, respectively (Ye et al., 1993). $^{40}Ar/^{39}Ar$ ages for white micas from the shear decollement zone between the melange zone and Hongan HP zone on the south are 229±4Ma to 235±2Ma (Webb et al., 1999). All these ages are consistent with the peak metamorphic ages of UHPM rocks from the Dabie-Sulu orogen. However, the eclogites involved in the melange zone have older metamorphic ages than the matrix and shear decollement.

The high-pressure mineral assemblage in eclogite from the Huwan melange zone is garnet + omphacite + rutile + glaucophane or barroisite + epidote + phengite + quartz. No coesite or pseudomorph after coesite has been found in this eclogite. Compositional zonation in the garnet is evident: the core contains abundant mineral inclusions of Na-Ca-amphibole, epidote, quartz, and albite; the rim is virtually free of inclusions. This zoning pattern reflects a progressive metamorphism and chemical disequilibrium between the core and rim of a garnet. Most of the eclogites have experienced intense retrograde metamorphism. The retrograde minerals include hornblende, barroisite, epidote and albite (Liu et al., 1996).

Ye et al. (1980) and Liu et al. (1996) have analyzed mineral chemistry of the eclogites from this zone and concluded that they are cold eclogites (T = 570 to 680℃ and P = 10 to 15 kb). Jian et al. (1997) reported zircon U-Pb isotopic ages of the eclogites from the Xiongdian village. Four fractions of yellowish, prismatic zircon each are concordant ranging from 373 to 400Ma within analytical uncertainties. A colorless round zircon with numerous small fluid inclusions yields a concordant age of 302±2Ma. They interpret the oldest concordant age of 400±2 Ma as the age of HP metamorphism and the youngest concordant age of 302±2Ma as the age of retrograde metamorphism. Recent ion microprobe (SHRIMP) data on zircon and cathodoluminescence (CL) of the zircon grains from the Xiongdian show that the inherited core in zircon grain with clear oscillatory zoning yields an age of 424±5Ma, and overgrowth rim of zircon yield an age of 301±13Ma (Jian et al., 2000). Zircons with unclear zoning are dated as 335±2 Ma to 408±8 Ma (Jian et al., 2000). These data clearly indicate two stages of zircon growth: the first stage at 424±5Ma that produced oscillatory zoning and probably occurred during crystallization from a magma; the second stage at 301±13Ma that is probably associated with HP metamorphism. The other ages ranging from 335 to 408Ma may represent "mixed ages" due to incomplete expulsion of radiogenic lead from metamict zircon during HP metamorphism. Therefore, we suggest that the Xiongdian eclogite from the Huwan melange zone was formed at around 301Ma instead of 424Ma, and its protolith is the basaltic rocks of Silurian (424±5Ma).

We have analyzed the trace element compositions of the Xiongdian eclogites (see Table 4). Though their higher SiO_2

Table 4. Major element (%) and trace element (ppm) compositions of eclogites from the Huwan tectonic melange zone*

Elements	Hujiawan eclogite				Xiongdian eclogite		
	95HN-S-8	95HN08	95HN-S-9	95HN-S-10	95HN-S-15	95HN-S-16	95HN-S-18
SiO_2	47.40		46.89	50.05	57.07	57.22	53.02
TiO_2	0.97		0.46	0.46	0.38	0.33	0.33
Al_2O_3	17.60		12.89	14.17	15.07	13.86	13.85
Fe_2O_3	2.30		2.57	4.54	1.42	1.35	1.53
FeO	10.37		7.86	4.17	5.79	5.59	5.33
MnO	0.233		0.193	0.114	0.13	0.15	0.14
MgO	6.02		10.75	7.56	5.75	5.50	5.52
CaO	11.84		14.69	12.99	9.29	11.10	13.85
Na_2O	1.62		1.16	3.22	3.35	3.34	2.23
K_2O	0.27		0.18	0.26	1.14	0.14	0.11
H_2O^+	1.53		2.11	1.81	0.38	0.05	1.04
CO_2	0.17		0.30	0.08	0.68	0.96	2.76
P_2O_5	0.044		0.018	0.028	0.06	0.09	0.10
Total	100.37		100.07	99.45	100.51	99.68	99.81
TFe_2O_3	13.82		11.30	9.17	7.85	7.56	7.45
Ti	3703	2037	2028	1098	2280	1980	1980
Cr	67.21	385.7	404.0	285.0	428	704	705
Co	33.82	47.03	43.35	33.88			
Ni	77.93	159.20	145.45	138.68	88	116	110
Cu	74.56	41.71	17.10	32.43			
Zn	81.48	68.58	64.55	72.19			
Rb	7.67	4.13	3.97	6.47	31	6	7
Sr	582.3	184.2	340.1	1416	149	345	396
Y	27.88	11.53	14.47	16.45	11.23	8.50	9.01
Zr	54.42	12.37	24.11	32.89	53	60	40
Nb	2.35	0.56	0.97	1.93	4	4	4
Sn	1.97	1.12	0.79	1.99			
Cs	0.27	0.25	0.32	0.50			
Ba	88.80	61.05	64.82	145.21	618	105	44
La	20.78	2.12	2.72	8.79	2.5	3.08	4.00
Ce	48.94	7.31	8.26	19.56	5.86	6.53	8.79
Pr	6.37	1.52	1.46	2.86	0.70	0.87	1.10
Nd	29.43	7.40	7.9	14.18	3.76	4.24	5.34
Sm	6.71	2.56	3.22	5.08	0.92	1.26	1.53
Eu	2.65	0.85	1.02	1.50	0.30	0.52	0.62
Gd	7.69	2.21	2.60	6.72	1.21	1.43	1.69
Tb	1.13	0.48	0.55	0.94	0.25	0.23	0.27
Dy	6.15	2.60	3.29	5.20	1.71	1.39	1.51
Ho	1.31	0.60	0.85	0.78	0.38	0.29	0.32
Er	3.24	2.10	2.36	1.83	1.10	0.86	0.87
Tm	0.72	0.44	0.32	0.44	0.18	0.15	0.15
Yb	3.47	1.94	2.86	3.19	1.16	0.86	0.86
Lu	0.75	0.32	0.46	0.41	0.20	0.16	0.15
Hf	2.68	1.21	1.94	1.86			
Ta	0.41	0.56	0.15	0.40			
Pb	14.76	6.80	9.53	11.98	14	25	36
Bi	0.11	0.47	<0.0086	1.10			
Th	0.99	0.20	0.22	1.01	2	3	3
U	0.30	0.14	0.19	2.14	1	1	2

* The major elements were obtained at the Institute of Geophysical and Geochemical Exploratory Techniques, Chinese Academy of Geological Sciences, by X-ray fluorescence analysis except CO_2 and H_2O which were obtained by nonaqueous titration and gravimetric analysis respectively. Trace elements of the Hujiawan eclogites were analyzed by ICP-MS at the Institute of Geology, Chinese Academy of Sciences; The Rare earth elements of the Xiongdian eclogites were analyzed at the Geological Institute of Hubei Province by ICP and their other trace elements were obtained at the Institute of Geophysical and Geochemical Exploratory Techniques by X-ray fluorescence analysis.

Table 5. Sr and Nd isotopic compositions of eclogites from Huwan tectonic melange zone*

Sample No.	Location	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$(^{87}Sr/^{86}Sr)_I$	Sm (ppm)	Nd(ppm)	$^{147}Sm/^{144}Nd$	$^{134}Nd/^{144}Nd$	$\varepsilon_{Nd}(t)$
95 HN-S-8	Hujiawan	8.361	584.7	0.0416	0.704752 ± 24	0.704529	6.315	23.69	0.1613	0.512489 ± 13	-1.5
95 HN-S-9	Hujiawan	4.724	355.2	0.0387	0.705253 ± 19	0.705045	1.557	6.118	0.1539	0.512502 ± 19	-1.0
95 HN-S-10	Hujiawan	4.153	1452	0.0083	0.709235 ± 21	0.709190	3.836	11.73	0.1978	0.512580 ± 9	-1.2
Hy23-1**	Xiongdian						1.09	3.29	0.2006	0.512909 ± 2	+ 5.1

* The Sr and Nd isotope data of eclogites from Hujiawan were obtained at modern analysis center, Nanjing University, following procedures described in Table 2. The initial $(^{87}Sr/^{86}Sr)_I$ and $\varepsilon_{Nd}(t)$ are corresponding to metamorphic age of 301 Ma.

** The Nd isotopic data were quoted from Jian et al. (1997).

Table 6. U-Pb isotopic compositions of zircon from the Hujiawan eclogite (95HN-S-8)*

Fractions		Wt.	U	Pb	Pb com.	Isotope atomic ratios ± 2σ					Age ± 2σ (Ma)		
No.	Properties	(μg)	(ppm)	(ppm)	(ng)	$^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
1	Colorless, clear round	10	317	24	0.016	785	0.3050	0.06005 ± 186	0.4484 ± 196	0.05416 ± 155	375.9 ± 12	376.2 ± 16	377.88 ± 11
2	Light yellow, clear round	10	488	33	0.022	864	0.1720	0.60029 ± 154	0.4509 ± 161	0.05423 ± 125	377.4 ± 10	377.9 ± 3	380.7 ± 9
3	Colorless, clear short prismatic	10	191	18	0.011	944	0.1475	0.08623 ± 379	0.7004 ± 421	0.5891 ± 223	533.2 ± 23	539.0 ± 32	563.9 ± 22
4	Colorless, clear long prismatic	20	122	12	0.001	13025	0.09121	0.1028 ± 6	0.8578 ± 461	0.06053 ± 355	630.7 ± 3	628.9 ± 34	622.4 ± 31
1+2	average										376.8 ± 7.3	377 ± 10	379.5 ± 6.7

*The U-Pb isotopic analysis was conducted in the Tianjin Institute of Geology and Mineral Resources. ^{205}Pb-^{235}U spike is used for fractions 1, 2, 3 and ^{208}Pb-^{235}U spike is used for fraction 4. Blanks of whole chemical procedure are: Pb = 30 pg, U = 2 pg, $^{206}Pb/^{204}Pb$ ratios has been corrected for blank and spike, other isotope atomic ratios are for radiogenic Pb. Common Pb correction and data processing were conducted using software PBDAT (1989) and ISOPLOT provided by Ludwig.

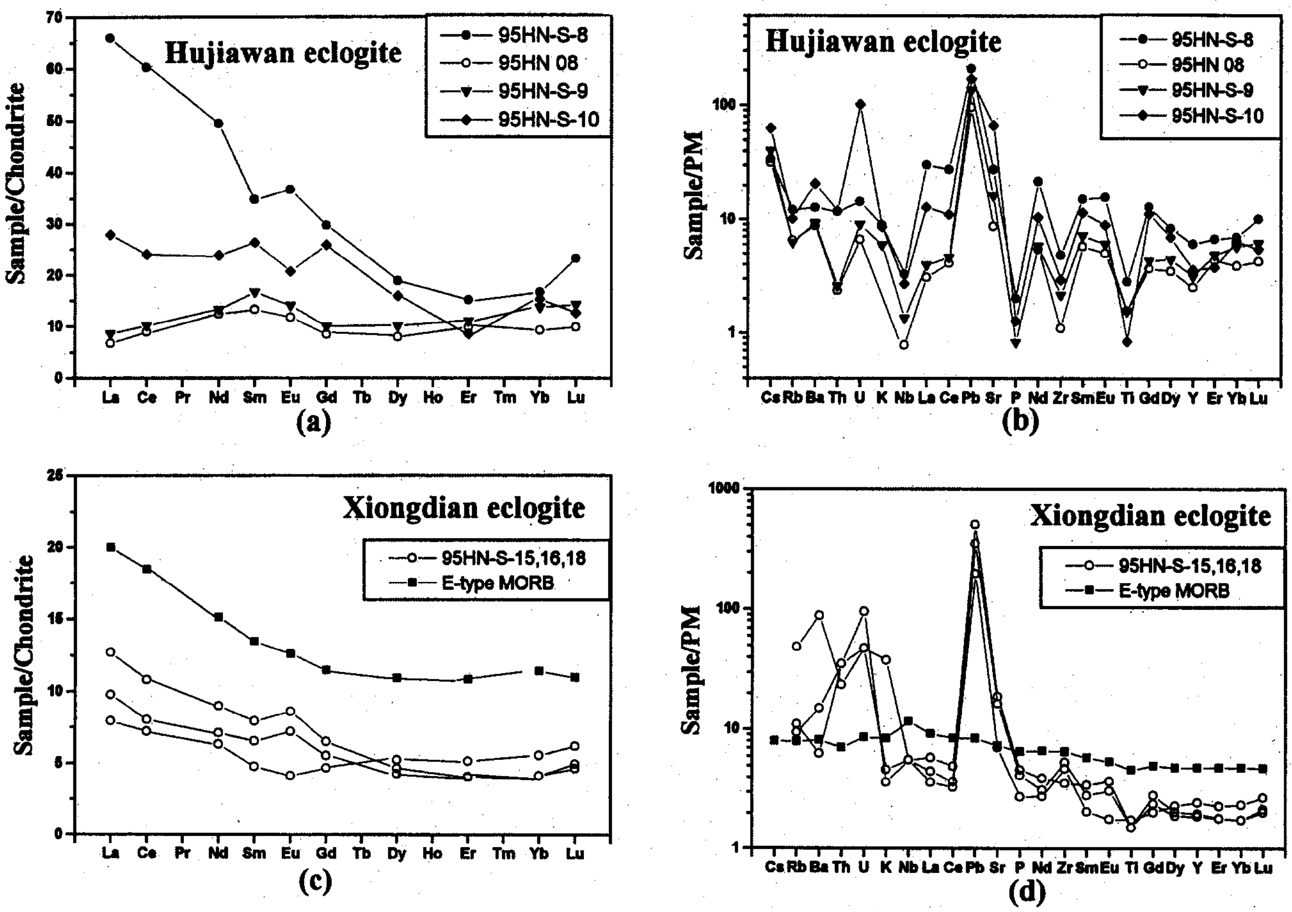

Fig. 8. Chondrite-normalized REE patterns (a and c) and primitive mantle normalized spidergrams (b and d) for eclogites from the Xiongdian and Hujiawan in Huwan tectonic melange zone. Except the mobile elements (Rb, Ba, K, Pb, Sr), REE and other trace element patterns of the Xiongdian eclogite are similar to E-MORB (c and d). Though the Hujiawan eclogites have various REE patterns including LREE depletion to LREE enriched (a), all of them are characterized by negative anomalies of Nb, P, Zr, Ti in spidergrams (b).

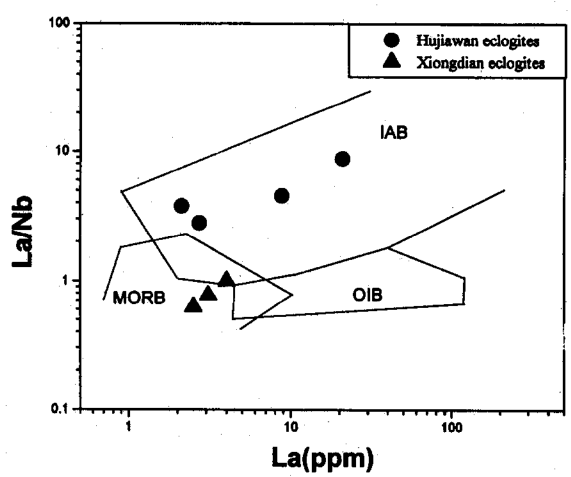

Fig. 9. La/Nb-La plot showing that the Xiongdian eclogites are characterized by lower La/Nb ratio, falling in the MORB field, while the Hujiawan eclogites are characterized by higher La/Nb ratio, falling in the IAB field (after Li et al., 1993).

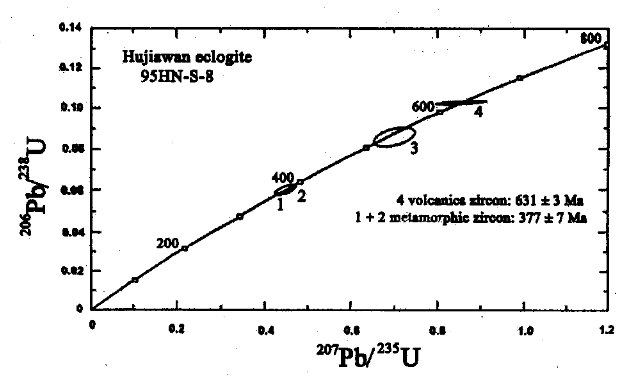

Fig. 10. Concordia diagram showing zircon analyses for sample 95HN-S-8, an eclogite from Hujiawan located in Huwan tectonic melange zone. Two fractions (1+2) of round metamorphic zircons yield a concordant age of 377±7Ma and the prismatic zircon (fraction 4) yields a concordant age of 631±3Ma.

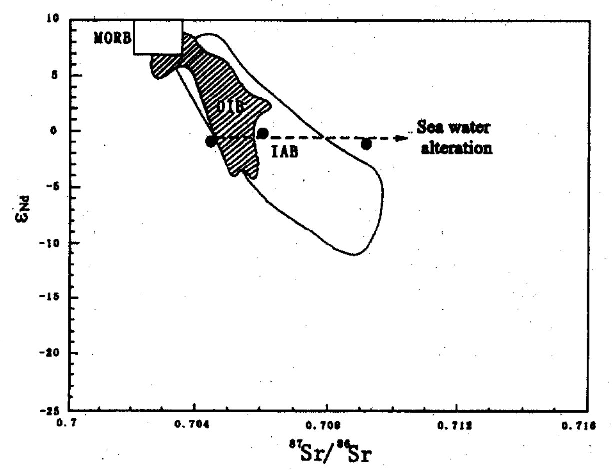

Fig. 11. ε_{Nd} vs $^{87}Sr/^{86}Sr$ diagram showing that the initial Nd and Sr isotopic compositions of eclogites from Hujiawan are similar to those of island arc basalts and characterized by sea water alteration. The fields of MORB, OIB and IAB are estimated at 300Ma based on the data from Zindler and Hart (1996) and Davidson (1983).

contents (53 to 57%) are similar to those of basaltic andesite, their high Cr (428 to 705ppm) and Ni (88 to 116ppm) contents are not similar to those of island-arc basalt and andesite. Their primitive mantle normalization pattern with slightly LREE enrichment and no Nb negative anomalous is similar to that of E-MORB (see Fig. 8). The Xiongdian eclogites are also plotted in the MORB field in La/Nb-La diagram (Fig. 9). The initial ε_{Nd} value at the metamorphic time (301 Ma) of the Xiongdian eclogite is +5.1 (see Table 5). If its Sm/Nd ratio has not been changed during HP metamorphism, it can be considered as ε_{Nd} value of the protolith of the Xiongdian eclogite because its whole rock $^{147}Sm/^{144}Nd$ ratio of 0.2006 is close to the average chondrite $^{147}Sm/^{144}Nd$ value of 0.1967 (Table 5). This high initial ε_{Nd} value (+5.1) is in contrast with the very low ε_{Nd} value (−5 to −17.7) of the coesite-bearing eclogites from the Southern Dabie zone (Li et al., 1993). The higher ε_{Nd} value suggests that the protolith of the Xiongdian eclogite may be a part of oceanic crust which was derived from a deplete mantle with little contamination of continental crust.

However, the trace element pattern of another eclogite lense in the Hujiawan village located to the north of the Xiongdian shows the typical feature of island arc basalt with negative Nb, P, Zr and Ti anomalies in spiderdiagram (see Figs. 8 and 9). We also obtained several U-Pb zircon ages for the Hujiawan eclogite using conventional U-Pb zircon dating method (see Table 6 and Fig. 10). Two fractions (1 and 2) of round metamorphic zircons yield a concordant age of 377±7Ma and the prismatic zircon (fraction 4) yields a concordant age of 631±3Ma. If the Hujiawan eclogite and the Xiongdian eclogite experienced the HP metamorphism at the same time, the age of 377±7Ma may represent a "mixed age", and the real metamorphic age of the Hujiawan eclogite could be about 301Ma. However, its concordant age of 631±3Ma suggests that the protolith age of the Hujiawan eclogite may be older than the Xiongdian eclogite. Their initial ε_{Nd} values at 301Ma (−1.0 to −1.5) (Table 5) are lower than that of the Xiongdian eclogite. Their Sr and Nd isotope compositions fall in the island arc basalt (IAB) field and indicate seawater alteration (Fig. 11). These data suggest that the protolith of the Hujiawan eclogite is different from that of Xiongdian eclogite and may be late Proterozoic island arc basalt erupted below the sea level.

All of the available data suggest that the Huwan tectonic melange zone may be formed in the early Triassic. The eclogites involved in this melange zone were formed in Carboniferous and had different protoliths, such as middle Paleozoic oceanic crust (the Xiongdian elcogite) and late Proterozoic island arc basalt. Since the Huwan tectonic melange zone directly contacts the Dingyuan formation (the Paleozoic magmatic arc) on the north, it should be the northmost margin of the SCB. Therefore, the Huwan melange zone could be a Triassic suture between the NCB and SCB in the western part of the Dabie orogen. The eclogites involved in this melange zone could be formed by oceanic subduction during the late Paleozoic (Carboniferous). Some island arc basalt in fore-arc region could be scraped off the island arc crust by subducting oceanic plate and subducted with the oceanic crust into the depth. However, as mentioned above, the geological data for the Beihuaiyang zone suggest that the oceanic subduction underneath the NCB could be terminated in the Devonian. In addition, the metamorphic age of 301Ma for the eclogites from the Huwan melange zone is consistent with the $^{40}Ar/^{39}Ar$ age of 316±1Ma for hornblende from the metamorphosed flysch formation of the Xinyang Group in the Tongbai area (Zhai et al., 1998) and $^{40}Ar/^{39}Ar$ age of 314±6 Ma of biotite from the Shangdan suture in Qinling area (Mattauer et al., 1985). Therefore, it is also possible that the Huwan tectonic melange zone may be formed by collision between the NCB and a possible microcontinent (similar to the South Qinling?) in the early Carboniferous. However, the difficulty in this interpretation is that no such a micro-continent has been identified in the Dabie orogen. More studies are needed to fully understand the tectonic setting of the Huwan melange zone, thus it is safe to say that the Huwan tectonic melange zone is the northmost boundary of the SCB in the western part of the Dabie orogen.

5 Northern Dabie Complex zone: a part of subducted continental crust of the SCB

Northern Dabie complex zone (or Northern Dabie zone) is mostly exposed in the eastern part of the Dabie orogen (Fig. 1), and is bounded by the Shang-Ma fault on the west (⑥ in Fig. 1) and Tan-Lu fault on the east (Fig. 1). It is separated from the Beihuaiyang zone by the Tongbai-Mozitan fault (② in Fig. 1) on the north and from the Hong'an-Susong high pressure and southern Dabie UHPM zones by the Xishui-Yingshan and Wuhe-Shuihou ductile shear zones on the south (⑤ and ③ in Fig. 1) (Dong et al., 1993; Suo et al., 1993; Cong et al., 1994). The Northern Dabie zone is composed mainly of felsic gneiss and migmatite with minor metapelite, marble, amphibolite, magnetite quartzite, quartzite, granulite and ultramafic rocks. Three large granitic batholiths of Cretaceous ages (120 to 125Ma) are exposed in this zone, e.g. the Tiantangzhai (T), Baimajian (B) and Zhuboyuan (Z) granites (Fig. 2). Similar K-Ar ages for K-feldspar from migmatite with high-K leucosomes (98 to 121Ma)(Chen et al., 1991) and Rb-Sr whole-rock isochron age for monozonitic migmatitie (111.5±4Ma)(Jian et al., 1996) suggest that the high-K leucosomes in migmatite and the Cretaceous granite may be formed at the same time. There are two kinds of gneiss: one is deformed diorite-granodiorite, the other is banded gneiss with strong foliation. Recent U-Pb zircon datings suggest that the deformed diorite-dacite intrusions, i.e. "orthogneiss", are crystallized in Cretaceous (Xue et al., 1997; Hacker et al., 1998) while the protoliths of the banded or mylonite gneiss were formed in late Proterozoic (757±1Ma and 707±42Ma) (Xue et al., 1997; Xie et al., 2001). The tectonic setting of the Northern Dabie zone before or during the Triassic collision is an important issue.

There are two kinds of ultramafic rocks in the Northern Dabie zone. One is the Alpine type peridotites, consisting of harzburgite, dunite and minor amphibole pyroxenite veins. These ultramafic bodies are mainly distributed on the northern margin of the Northern Dabie zone (see Fig. 2). They are strongly deformed and thus were tectonically emplaced into mylonite gneiss. For example, the Raobazhai ultramafic massif was emplaced in solid state into migmatites of the Northern Dabie zone. Country rocks near the contact zone are strongly mylonitized. Foliations are well developed along the margin of the massif and a mylonite zone crosscuts the massif. It has been generally accepted that the Raobazhai ultramafic massif was a fragment of the lithosphere mantle (Q. Zhang et al., 1995; Li et al., 1998). The trace element compositions with Nb negative anomalous and the isotopic compositions of the garnet-pyroxenite and amphibole-pyroxenite veins in the Raobazhai massif suggest that the lithospheric mantle has been metasomatized by fluid related to oceanic subduction (Q. Zhang et al., 1995; Li et al., 1993). Its not very low initial ε_{Nd} value of −2.7 (Li et al., 1993) suggests that the related oceanic subduction could occur during the Paleozoic time. Therefore, the Raobazhai massif could be derived from the mantle wedge underneath the overthrust crust of the NCB. The Sm-Nd mineral isochron age of 244±11Ma for the garnet-pyroxenite from the Raobazhai massif suggests that the tectonic emplacement of the ultramafic body occurred during the Triassic collision between the NCB and SCB (Li et al., 1989, 1993). The other kind of mafic-ultramafic rocks are pyroxenite-gabbro intrusions of Cretaceous ages (130 to 120Ma), such as Zhujiapu, Renjianwan and Zhongguan pyroxenites and Jiaoyan gabbro (①, ③, ④ and ⑤ in Fig. 2) (Hacker et al., 1998; Li et al., 1999b; Jahn et al., 1999). These rocks were intruded into the banded gneiss but intruded by granitic dykes.

Since no UHP rocks has been observed in the Northern Dabie zone until very recently, various tectonic settings have been proposed for this zone, such as metaophiolite melange in the suture (Xu et al., 1992b), island arc near the NCB (Dong et al., 1993; Cong et al., 1994), a thrust plane behind the eclogite zone in the subducted continental basement of the SCB (Okay and Sengör, 1993) or a thrust plane in the front of the eclogite zone in subducted continental crust (Maruyama et al., 1994), and the NCB hanging wall during the Triassic subduction of the SCB (Zhang et al., 1996). Recent discovery of eclogite in the Northern Dabie zone (Xu et al., 2000; Liu, 2000) and its isotopic dating (Liu et al., 2000, 2001) greatly help us to understand the tectonic setting of the Northern Dabie zone.

There are two kinds of eclogites in the Northern Dabie zone. One occurred in foliated peridotite, such as Raobazhai and Huangweihe massifs (② and ⑦ in Fig. 2) (Liu, 2000; Xiao et al., 2001). The other one is in banded gneiss, such as Baizhangyan and Huazhuang eclogites (⑧ and ⑨ in Fig. 2) (Liu, 2000). All these eclogites are located on the north margin of the Northern Dabie zone (see Fig. 2). Omphacite with high Na_2O content up to 7.6~7.9% are preserved as inclusions in garnet. Omphacites which are outside of garnet were mostly retrograded to symplectite or diopside (Xu et al., 2000). Other scientists have observed some eclogite-facies relics, such as omphacite (Xiao et al., 2001) and microstructure of oriented quartz needles in Ca-Nd clinopyroxene (Tsai et al., 1998). So far no coesite has been found in these eclogites, thus it is unclear whether the eclogites suffered the UHP metamorphism. After the HP metamorphism, those eclogites were firstly retrograded at granulite-facies (T = 845 to 900°C and P = 7 to 11kb), and then retrograded to amphibolite (Xu et al., 2000; Xiao et al., 2001). The granulite-facies can be identified by hypersthene in symplectite (Liu, 2000; Xiao et al., 2001).

An U-Pb age for zircon from Raobazhai eclogite (230±6Ma) (Liu et al., 2000) and Sm-Nd mineral isochron ages for Raobazhai garnet pyroxenite (garnet + diopside, 244±11Ma) (Li et al., 1989) and Huangweihe eclogite (garnet + omphacite, 210±6Ma and 214±6Ma) (Liu et al., 2001) suggest that the eclogites in Northern Dabie zone were formed in the Triassic. The eclogite-bearing foliated peridotites could be scraped off the overlying lithospheric mantle by subducting continental crust and were subducted with the continental crust into depths. Hence, the northern margin of the Northern Dabie zone, where the foliated peridotites and eclogites are developed, could be close to the suture zone between the NCB and SCB. Recent U-Pb zircon dating suggests that the banded gneiss in the Northern Dabie zone, which are country rocks of the eclogite, also experienced the Triassic (226±6Ma and 229±18Ma) metamorphism (Liu et al., 2000; Xie et al., 2001). The different retrograde metamorphic history between the Northern Dabie eclogite and Southern Dabie eclogite as well as the older Nd model ages (2.0 to 2.6Ga) for the orthogneiss in the Northern Dabie zone than those in the Southern Dabie zone (see Table 3, Fig. 10A) suggest that the Northern and Southern Dabie zones are two different thrust planes in subducted continental crust. They have the same HP or UHP metamorphic ages, but may have different exhumation histories. The similar conclusion has been drawn by Zheng et al. (2001) from the oxygen isotope study of granulites from Northern Dabie zone. Therefore, the Wuhe-Shuihou ductile shear zone (③ in Fig.1), separating the Northern Dabie and Southern Dabie zones, is a fault in the subducted continental crust instead of the suture between the NCB and SCB. In view of the above conclusion that lower unit of the Beihuaiyang zone was the active continental margin of the NCB, the suture between the NCB and SCB could be located along the boundary between the North Dabie zone and Beihuaiyang zone in the eastern part of the Dabie orogen.

6 Conclusions

(1) The protoliths of metabasic volcanic rocks from the Dingyuan formation of the Beihuaiyang zone in the Dabie orogen is subalkaline basalt and belong to calc-alkaline series. These rocks have typical island arc geochemical features, e.g., negative Nb, Ti and P anomalies but positive Ba, Pb and Sr anomalies in trace element spiderdiagram as well as high La/Nb, Ba/Nb and Th/Nb ratios.

The Sm-Nd and Rb-Sr isochrons of the meta-volcanic rocks from the Dingyuan formation yield consistent ages of 446±23Ma and 444±31Ma, respectively. These ages may indicate that their formation age is comparable to the Danfeng island arc volcanics in the North Qinling belt. This is the first evidence for the Palezoic magmatic arc in the Dabie orogen.

The geochemical features and isotopic ages of the Dingyuan volcanics as well as their tectonic setting at convergent plate boundary suggest that the Beihuaiyang zone once could be an magmatic arc on the southern active continental margin of the NCB in the Ordovician to Silurian. Therefore, the suture between the NCB and SCB should be to the south of the Dingyuan formation in the northwestern part of the Dabie orogen.

(2) The Nd isotope model ages (T_{DM}) of metasediments from the Foziling Group range from 1.7 to 1.9Ga, which are younger than the Nd model ages (1.9 to 2.1Ga) of the Northern Paleozoic sedimentary cover of the SCB and those of the North Qinling basement rocks. This suggests that more Phanerozoic volcanics were involved in the sedimentary rock of the Foziling Group, indicating an active continental margin setting of the Beihuaiyang zone in the Devonian. However, if a micro-continent similar to the South Qinling belt would once exist in the Dabie area, the Beihuaiyang zone could become a remnant basin in the Devonian, which could receive detritus from both the Northern and Southern continental margins.

(3) The eclogites in the Huwan tectonic melange zone were formed in the Carboniferous (~301±13Ma). The protolith of eclogite from Xiongdian could be Silurian (424 ± 5 Ma) oceanic crust, while the protolith of eclogite from Hujiawan is more likely to be late Proterozoic island arc basalt. However, the synkinematic minerals from the argilitic matrix and shear decollement faults of the melange zone were formed in the Triassic. Two alterative interpretations to the tectonic setting of the Huwan tectonic melange are possible: (a) it could be a Triassic suture between the NCB and SCB, and the eclogites involved in this melange zone were formed by oceanic subduction before continental collision; or (b) it could be formed by collision between the NCB and a possible micro-continent in the Carboniferous. Further studies are needed to test whether there was a micro-continent between the NCB and SCB during the Paleozoic time in the Dabie area.

(4) The discovery of the Triassic eclogite in the Northern Dabie zone suggests that the Northern Dabie zone is a part of the subducted continental crust of the SCB. The North Dabie high T/P metamorphic zone, Southern Dabie UHPM zone and Susong-Hongan HP metamorphic zone may represent three thrust planes of the subducted continental crust. In light of the conclusion (1), the suture between the NCB and SCB in the eastern part of the Dabie orogen could be located on the boundary between the Northern Dabie zone and Beihuaiyang zone.

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