ARTICLES

Chinese Science Bulletin 2004 Vol. 49 No. 8 848—852

Zircon U-Pb SHRIMP ages of eclogites from the North Qilian Mountains in NW China and their tectonic implication

SONG Shuguang[1], ZHANG Lifei[1], NIU Yaoling[2], SONG Biao[3], ZHANG Guibing[1] & WANG Qianjie[1]

1. MOE Key Laboratory of Orogenic Belts and Crustal Evolution, Department of Geology, Peking University, Beijing 100871, China;
2. Department of Geology, University of Houston, Houston, TX 77204, USA;
3. Beijing SHRIMP Centre, Institute of Geology, CAGS, Beijing 100037, China

Correspondence should be addressed to Zhang Lifei (e-mail: lfzhang@pku.edu.cn)

Abstract Cathodoluminescence (CL) imaging and ion microprobe (SHRIMP) U-Pb dating were carried out for zircons from eclogites in the North Qilian Mountains. The results show weighted mean ages of 463 ± 6 Ma and 468 ± 13 Ma for two samples, respectively. These ages are the earliest record of Caledonian high-pressure metamorphism in the North Qilian Mountains, and they may represent the timing of eclogite-facies metamorphism when the oceanic crust was subducted to mantle depths in this orogenic belt.

Keywords: high-pressure metamorphism, eclogite, zircon age, North Qilian Mountains.

DOI: 10.1360/03wd0517

The North Qilian Mountains at the boundary between Gansu and Qinghai Provinces are a famous Caledonian plate suture zone in the northwestern China. This suture zone is 80 to 100 km wide and extends in the NW direction parallel to the North Qaidam UHP belt in the south[1,2]. It consists predominantly of ophiolite, island-arc complex and high-presure metamorphic rocks[3—8], and shows typical features of Pacific-type[9] (or B-type) subduction zone. Spatially, the high-pressure rocks can be subdivided into high-grade blueschist belt and low-grade blueschist belt[5, 6]. The high-grade blueschist belt, which is located in the territory of Qilian County, occurs as three tectonic slices within the island-arc acid volcanic rocks (Fig. 1). It mainly consists of high-pressure blueschists of various protoliths, whereas eclogites occur as blocks in different size randomly scattered within the blueschists and are overprinted by late blueschist facies minerals. The low-grade blueschist belt is located in the Nine Springs, Sunan County, Gansu Province, and consists blueschists with low-temperature (<300℃) mineral assemblage of glaucophane, lawsonite, pumpellyite and aragonite[5,10].

The forming age of high-pressure rocks is one of the key problems concerned seriously by many researchers for tectonic evolution of the North Qilian Orogenic Belt. By using Ar-Ar dating method for glaucophane and phengite from the blueschists, some researchers have obtained ages ranging from 440 to 460 Ma[5,6,11—13], which may represent the metamorphic to cooling ages of the blueschists. Occurrence of the Silurian remnant-sea flysch formation[6] reflects that the ancient Qilian Ocean has closed at the end of Ordovician era, which is consistent with Ar-Ar age of phengite from blueschist (448 ± 11 Ma) reported by Liou et al.[12]. However, due to limit of dating methods, reliable isotopic age for eclogite has not been obtained so far. By using CL and in situ zircon SHRIMP dating techniques, this paper reports precise zircon U-Pb ages for eclogites, and the results play an important role in understanding the processes of oceanic subduction and high-pressure metamorphism in the North Qilian Orogenic belt.

1 Samples and analytical techniques

The studied two samples were collected from Upper Xiangzigou (QS45), about 40 km west of Qilian town, and Baijingsi (2Q27), ~40 km east of Qilian town, respectively (Fig. 1). Rocks are massive with weak foliation and show medium-grained granular texture. The peak eclogite-facies mineral assemblage is garnet + omphacite + phengite + rutile. Omphacite in all samples was overprinted by late blueschist-facies retrograde glaucophane, which suggests that eclogite facies metamorphism is earlier than blueschist facies. Electron microprobe analyses reveal that garnet is characterized by high FeO and low MgO in a compositional range of almandine 61.5—65.8 mol%, grossular 23.8—28.3 mol% and pyrope 7.3—9.0 mol%. Jadeite content of omphacite varies in 35.8—41.4 mol%, and Si in phengite, from 3.42—3.48 p.f.u.. The Grt-Omp-Phn geothermobarometer[1)] yielded peak eclogite-facies conditions at P = 18—25.6 GPa and T = 500—550℃.

Zircon separation was performed in a laboratory of Langfang Institute of Regional Geological Survey. Rocks were crushed and sieved to about 100 m for the separation. Zircon separation was done by combining magnetic and heavy liquid methods before finally hand-picked under a binocular microscope. Because of relative smaller and the possible gabbroic protolith, we only got several zircon grains from sample 2Q27. The zircon crystals were embedded in 25 mm epoxy discs together with standard TEM and then polished down to half sections. The internal zoning was examined using CL and BSE images at Peking University. The CL images were carried out on a FEI

1) Krogh-Ravna, E., Terry, M. P., Geothermobarometry of phengite-kyanite-quartz/coesite eclogites, Eleventh Annual V. M. Goldschmidt Conference, Abstract #3145, LPI Contribution No. 1088, Lunar and Planetary Institute, Houston (CD-Rom), 2001.

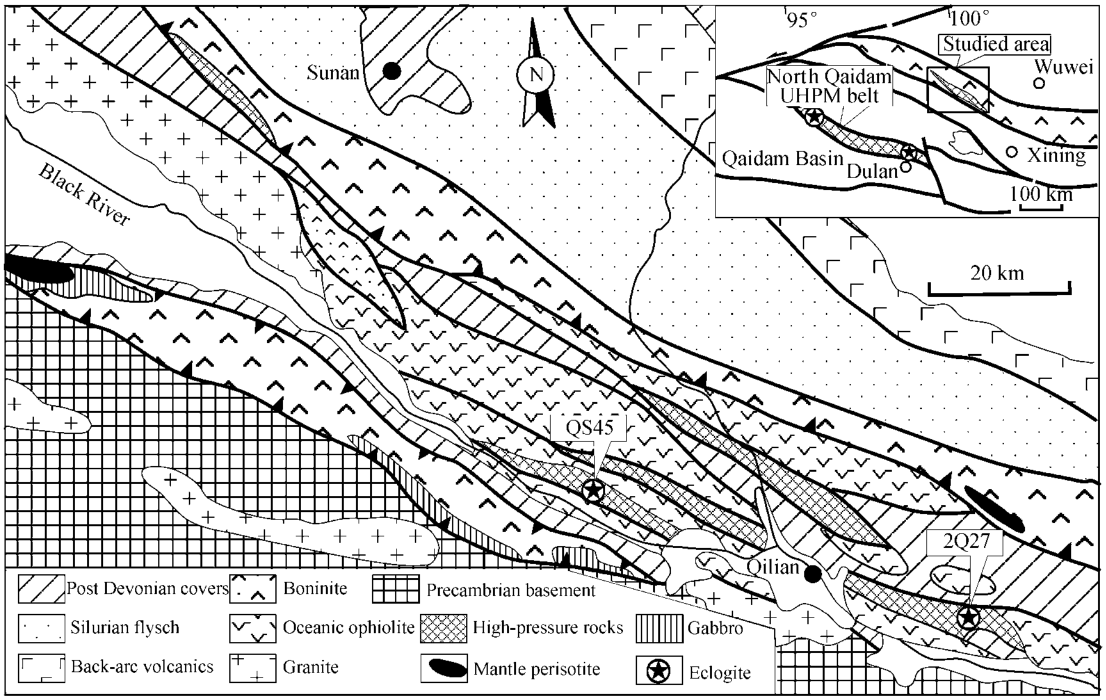

Fig. 1. Geological map of the middle part of the North Qilian Mountains and sample localities.

PHILIPS XL30 SFEG SEM with 2 min scanning time at condition 15 kV/120 μA. The zircons were analyzed for U, Th and Pb using SHRIMP Ⅱ at the Beijing SHRIMP Centre, Institute of Geology, CAGS. Instrument conditions and measurement procedures were the same as described by Compston[14]. The measured $^{206}Pb/^{238}U$ ratio in the samples was corrected using reference zircon standard SL13 from a pegmatite from Sri Lanka (572 Ma) and zircon standard TEM (417 Ma) from Australia. The reference zircon was analysed each fourth analysis. The common Pb component was estimated from ^{204}Pb counts, and the ages are weighted means with 2σ errors calculated using isoplot[15] at the 95% confidence levels.

2 Analytical results

Zircons from the two samples are rather uniform in grain size of 80—120 μm. They are ovoid-shaped with multifacet and show features of metamorphic origin[16]. CL investigations show that the inner structures are rather inhomogeneous. The luminescence of the major domains of all zircons shows rather heterogeneity in overgrown textures of fir-tree sector zoning, planar grow banding and radial sector zoning. These sector zonings are different from oscillatory bandings, and reflect that zircons have crystallized with fluctuating growth rate in a strongly changed growth environment[17]. Some zircons contain a small relict core (10—20 μm in diameter) with bright luminescence (Fig. 2(b)); only one relict core with clear magmatic oscillatory bandings in sample 2Q27 is large enough for SHRIMP analysis (Fig. 2(d)) and probably is the relict of the protolith.

The U-Th-Pb SHRIMP analyses for zircons from two eclogite samples QS45 and 2Q27 are listed in Table 1 and the graphically presented on Tera-Wasserburg (TW) diagrams in Fig. 3.

(ⅰ) Eclogite QS45 from Upper Xiangzigou. Sample QS45 from the Upper Xiangzigou to ~40 km west of the Qilian town has high content of zircon. In this paper, fifteen representative zircons were selected for analysis. U contents are ranging from 341 to 1328 ppm, and Th/U radios are 0.24—0.45. The fifteen zircons yielded apparent $^{206}Pb/^{238}U$ ages ranging from 449 to 479 Ma with a weighted mean at 463 ± 6 Ma (SMWD=0.4), which represents the forming age of eclogite and is correspondent to the middle to late Ordovician. In Tera-Wasserburg diagram (Fig. 3(a)), only one spot (QS45-7.1) departures the Concordia curve; its $^{207}Pb/^{206}Pb$ age is 727±38 Ma, probably reflecting a crustal contamination.

(ⅱ) Eclogite 2Q27 from Baijingsi. Because of less zircon grains in this sample, we have only obtained 5 effective data (Table 1). Three zircons yield concordant ages of 464—470 Ma with a weighted mean at 468±13 Ma (2σ) (MSWD = 0.1), the same as the age of sample QS45. Spot 2Q27-2.1 yields an apparent $^{206}Pb/^{238}U$ age of 422±21 Ma, which may represent the age of late greenschist-facies retrograde overprint. Spot 2Q27-2.1 is analyzed on a core that is observed to be a relict magmatic core under mi-

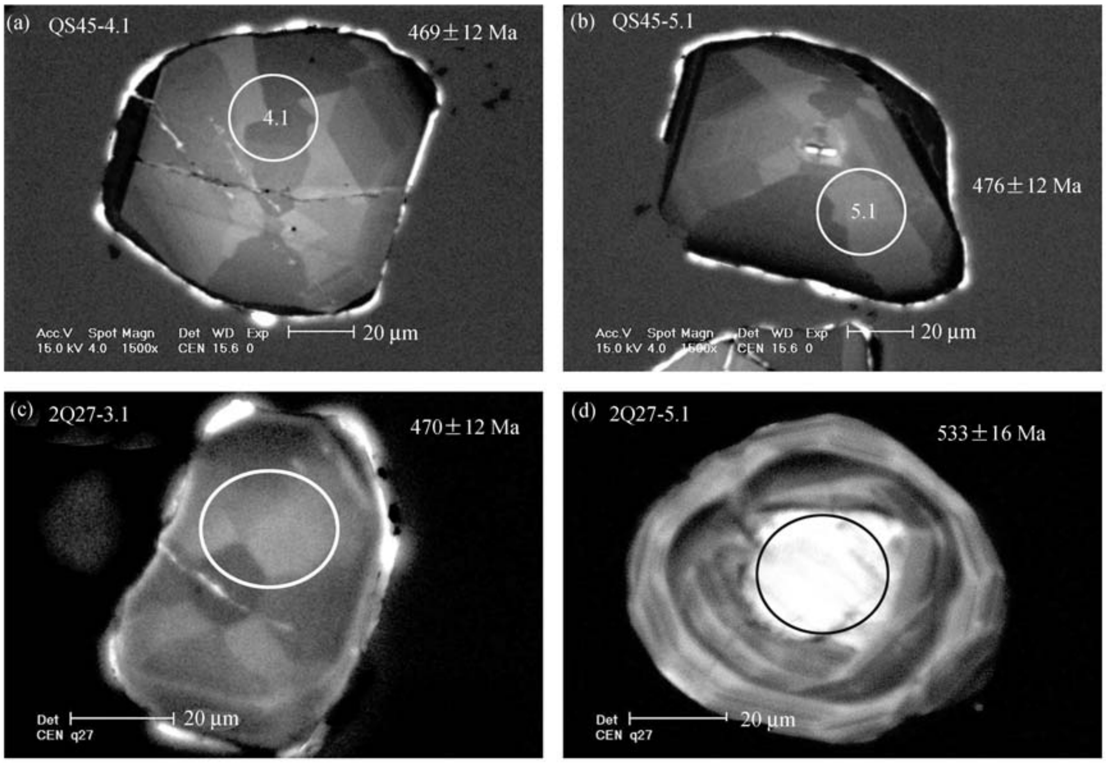

Fig. 2. Representative CL images of zircons from eclogites with dating positions and $^{238}U/^{206}Pb$ age.

Table 1 U, Th and Pb SHRIMP zircon data of eclogites from the North Qilian Mountains

Spot	U/ppm	Th/ppm	Th/U	Pb* /ppm	Common Pb (%)	$^{207}Pb^*/^{206}Pb^*$	$^{207}Pb^*/^{235}U$	$^{206}Pb^*/^{238}U$	$^{206}Pb/^{238}U$ age/Ma	$^{207}Pb/^{206}Pb$ age/Ma
QS45-1.1	343	126	0.37	21.8	0.32	0.0583 ± 0.0020	0.59 ± 0.025	0.0737 ± 0.0020	458 ± 12	540 ± 73
QS45-2.1	515	168	0.33	33.0	0.15	0.0594 ± 0.0009	0.61 ± 0.018	0.0745 ± 0.0019	463 ± 12	583 ± 33
QS45-3.1	474	150	0.32	31.4	−0.09	0.0598 ± 0.0010	0.64 ± 0.020	0.0772 ± 0.0020	479 ± 12	597 ± 37
QS45-4.1	350	113	0.32	22.7	0.18	0.0563 ± 0.0013	0.59 ± 0.020	0.0754 ± 0.0020	469 ± 12	465 ± 49
QS45-5.1	341	142	0.42	22.5	0.27	0.0593 ± 0.0014	0.63 ± 0.022	0.0766 ± 0.0020	476 ± 12	577 ± 50
QS45-6.1	982	427	0.43	62.5	0.16	0.0579 ± 0.0007	0.59 ± 0.017	0.0739 ± 0.0019	460 ± 11	528 ± 28
QS45-7.1	341	138	0.40	21.9	0.09	0.0636 ± 0.0012	0.65 ± 0.021	0.0746 ± 0.0020	464 ± 12	727 ± 38
QS45-8.1	1328	478	0.36	82.4	0.04	0.0580 ± 0.0006	0.58 ± 0.018	0.0722 ± 0.0021	449 ± 13	529 ± 21
QS45-9.1	474	114	0.24	30.2	0.19	0.0566 ± 0.0013	0.58 ± 0.020	0.0739 ± 0.0019	460 ± 12	477 ± 49
QS45-10.1	229	90	0.39	15.1	0.59	0.0576 ± 0.0021	0.60 ± 0.027	0.0761 ± 0.0020	473 ± 12	514 ± 81
QS45-11.1	381	142	0.37	24.2	0.28	0.0577 ± 0.0013	0.59 ± 0.022	0.0738 ± 0.0022	459 ± 13	520 ± 51
QS45-12.1	398	178	0.45	25.3	0.35	0.0571 ± 0.0016	0.58 ± 0.022	0.0738 ± 0.0019	459 ± 12	494 ± 60
QS45-13.1	367	155	0.42	23.6	0.46	0.0576 ± 0.0012	0.59 ± 0.020	0.0745 ± 0.0019	463 ± 12	513 ± 47
QS45-14.1	704	220	0.31	44.6	0.13	0.0577 ± 0.0010	0.59 ± 0.020	0.0736 ± 0.0022	458 ± 13	518 ± 37
QS45-15.1	403	159	0.39	25.6	0.16	0.0571 ± 0.0010	0.58 ± 0.019	0.0740 ± 0.0019	460 ± 12	496 ± 40
2Q27-2.1	621	335	0.54	36.1	0.11	0.0572 ± 0.0009	0.53 ± 0.016	0.0676 ± 0.0016	422 ± 11	499 ± 35
2Q27-3.1	510	133	0.26	33.1	0.00	0.0588 ± 0.0009	0.61 ± 0.019	0.0756 ± 0.0020	470 ± 12	561 ± 34
2Q27-4.1	372	146	0.39	24.2	0.11	0.0587 ± 0.0011	0.61 ± 0.020	0.0756 ± 0.0020	470 ± 12	556 ± 40
2Q27-5.1	1218	237	0.19	90.3	0.04	0.1099 ± 0.0024	1.31 ± 0.049	0.0863 ± 0.0026	533 ± 16	1798 ± 39
2Q27-6.1	644	182	0.28	41.3	0.14	0.0584 ± 0.0009	0.60 ± 0.018	0.0746 ± 0.0019	464 ± 12	543 ± 35

Pb^*, radiogenic lead; all errors are 1σ. Common lead is calibrated using measured ^{204}Pb.

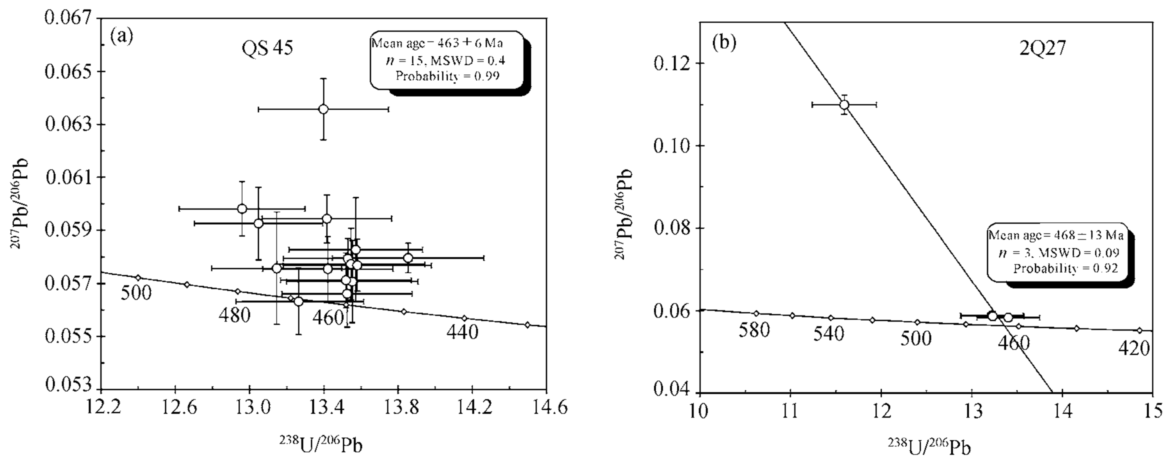

Fig. 3. Tera-Wasserburg diagram for zircon U-Pb ages of eclogite QS45 (a) and 2Q27 (b) from the North Qilian Mountains.

croscopy. In CL image, this core shows bright lumines may have been affected by metamorphic events. The U and radiogenic lead contents are high and it departures far from the Concordia curve in Fig. 2(b). The $^{206}Pb/^{238}U$ age of 533±16 Ma may represent the age of a modified protolith, whereas the $^{207}Pb/^{206}Pb$ age of 1798±39 Ma reflects information of crustal contamination on the protolith.

3 Tectonic implications

Zircons in the two eclogite samples are characterized by typical metamorphic origin. They formed under conditions at eclogite-facies high-pressure (1.8—2.5 GPa) and low-temperature (500—550℃) during subduction of the oceanic lithosphere. The high Th/U ratios (0.19—0.54) may be attributed to high Th content in the protolith.

Eclogite and blueschist are products of high-pressure metamorphism during oceanic plate subduction. A plausible model for initiation of the oceanic subduction is that a large ocean with cold and negative buoyant oceanic lithosphere is necessary for sinking into the asthenosphere due to its gravity[18—20]. It is consistent with the fact that a large amount of ophiolites with N-type and E-type MORB[7] occur in this suture zone. On the basis of zircon age and geochemical studies on the Precambrian basement rocks, Wan et al.[21] suggested that the North Qilian suture zone was the major boundary that separates the Alax Block to the north and the Qilian Block to the South. Yang et al.[22] reported zircon SHRIMP ages of 533—568 Ma for a gabbro from an ophiolite suite, suggesting that the Qilian Ocean existed at least in the Early Cambrian. Paleontological data also indicated that forming time of the oceanic ophiolite in this region was earlier than the Middle Cambrian[3, 23]. Zircons from two eclogite samples yielded $^{206}Pb/^{238}U$ ages of 463—468 Ma, representing ages of eclogite-facies metamorphism at depths greater than 60 km.

Zhang et al.[13] dated single-grain zircon U-Pb ages of 466 to 481 Ma for island-arc acid volcanic rocks near the locality of sample QS45. Xia et al.[4] reported Sm-Nd and Rb-Sr isochron ages of 445 to 486 Ma for island-arc shoshonite and basalt in Shihuigou, Yongdeng County. Thus, the metamorphic ages of eclogite are consistent with the forming ages of island-arc volcanic rock, reflecting that dehydration of eclogite-facies metamorphism caused mantle wedge partial melting and then formed volcanic rocks during the North Qilian oceanic subduction. These chronological data suggest that subduction of the ancient North Qilian ocean was initiated at the beginning of Middle Ordovician, which is concordant with the time when the North China Craton started to uplift and discontinuous sedimentation. Ar-Ar ages of glaucophane and phengite from blueschist range from 440 to 460 Ma[5,11—13], younger than ages of eclogite. This is consistent with petrological observations that the blueschist-facies metamorphism overprinted the eclogite-facies rocks. Combining with the well-developed Silurian remnant-sea flysch formation, we conclude that the Qilian Ocean was closed at the end of Ordovician.

Acknowledgements P. Jian, Y. S. Wan, Y. H. Zhang and H. Tao are thanked for their helps during ion microprobe analyses, and X. L. Liang for his help during CL investigation. We also thank two anonymous peer reviewers for their constructive comments, which led to a better presentation of the final product. This study was financially supported by the "973" Programme of China (Grant No. 1999075508), the National Natural Science Foundation of China (Grant Nos. 40372031, 40228003, 40325005 and 40272031) and post-doc foundation to Song Shuguang.

References

1. Song, S. G., Yang, J. S., Xu, Z. Q. et al., Metamorphic evolution of the coesite-bearing ultrahigh-pressure terrane in the North Qaidam, northern Tibet, NW China, Journal of Metamorphic Geology, 2003, 21: 631—644.[DOI]
2. Song, S. G., Yang, J. S., Liou, J. G. et al., Petrology, geochemistry and isotopic ages of eclogites in the Dulan UHPM terrane, the North Qaidam, NW China, Lithos., 2003, 70: 195—214.[DOI]

3. Xiao, X. C., Chen, G. M., Zhu, Z. Z., A preliminary study on the tectonics of ancient ophiolites in the Qilian Mountains, northwest China, Acta Geologica Sinica (in Chinese), 1978, 52: 287—295.
4. Xia, L. Q., Xia, Z. C., Xu, X. Y., Dynamics of tectono-volcano-magmatic evolution from North Qilian Mountains, China, Northwest Geoscience (in Chinese), 1995, 16: 1—28.
5. Wu, H. Q., Feng, Y. M., Song, S. G., Metamorphism and deformation of blueschist belts and their tectonic implications, North Qilian Mountains, China, Journal of Metamorphic Geology, 1993, 11: 523—536.
6. Song, S. G., Metamorphic geology of blueschists, eclogites and ophiolites in the North Qilian Mountains, 30th IGC Field Trip Guide T392, Beijing: Geological Publishing House, 1996, 1—40.
7. Zhang, Q., Sun, X. M., Zhou, D. J. et al., Characteristics and forming environment of orphiolites in the North Qilian Mountains and their tectonic implications, Advance in Earth Sciences (in Chinese), 1997, 12(4): 366—393.
8. Song, S. G., Tectonic evolution of subductive complex belts in the North Qilian Mountains, Advance in Earth Sciences (in Chinese), 1997, 12(4): 351—365.
9. Ernst, G., Subduction, ultrahigh-pressure metamorphism, and regurgitation of buoyant crustal slices——implications for arcs and continental growth, Physics of the Earth and Planetary Interiors, 2001, 127: 253—275.[DOI]
10. Wu, H. Q., Feng, Y. M., Huo, Y. G. et al., Discovery of lawsonite glaucophane schist and the signification in Sunan, Gansu, China, Geological Review (in Chinese), 1990, 3: 277—280.
11. Xiao, X. C., Tang, Y. Q., Re-exposition on plate tectonics of the Qinghai-Xizang Plateau, Bulletin of the Chinese Academy of Geological Sciences (in Chinese), 1986, (4): 7—20.
12. Liou, J. G., Wang, X. M., Colemen, R. G., Blueschists in major suture zones of China, Tectonics, 1989, 8(3): 609—619.
13. Zhang, J. X., Xu, Z. Q., Chen, W. et al., A tentative discussion on the ages of the subduction-accretionary complex/volcanic arcs in the middle sector of North Qilian Mountain, Acta Petrologica et. Mineralogica (in Chinese), 1997, 16: 112—119.
14. Compston, W., Williams, I. S., Kirschvink, J. L. et al., Zircon U-Pb ages for the Early Cambrian time-scale, Journal of Geological Society of London, 1992, 149: 171—184.
15. Ludwig, K. R., Isoplot: A plotting and regression program for radiogenic isotope data, USGS Open-File Report, 1991, 91—445.
16. Gebauer, D., Lappin, M. A., Grunenfelder, M., The age and origin of some Norwegian eclogites: A U-Pb zircon and REE study, Chemical Geology, 1985, 52: 227—248.
17. Vavra, G., Gebauer, D., Schmid, R. et al., Multiple zircon growth and recrystallization during polyphase Late Carboniferous to Triassic metamorphism in granulites of the Ivrea Zone (Southern Alps): An ion microprobe (SHRIMP) study, Contributions to Mineralogy and Petrology, 1996, 122: 337—358.[DOI]
18. Mueller, S., Phillips, R., On the initiation of subduction, Journal of Geophysical Research, 1991, 96: 651—665.
19. Bercovici, D., The generation of plate tectonics from mantle convection, Earth and Planetary Science Letters, 2003, 205: 107—121.[DOI]
20. Niu, Y., O'hara, M. J., Pearce, J. A., Initiation of subduction zones as a consequence of lateral compositional buoyancy contrast within the lithosphere: A petrological perspective, Journal of Petrology, 2003, 44: 851—866.[DOI]
21. Wan, Y. S., Xu, Z. Q., Yang, J. S. et al., Ages and compositions of the Precambrian high-grade basement of the Qilian Terrane and its adjacent areas, Acta Geologica Sinica, 2001, 75: 375—384.
22. Yang, J. S., Xu, Z. Q., Zhang, J. X. et al., Early Palaeozoic North Qaidam UHP metamorphic belt on the north-eastern Tibetan plateau and a paired subduction model, Terra Nova, 2002, 14(5): 397—404.[DOI]
23. Qinghai Bureau of Geology and Mineral Resources, Regional Geology of Qinghai Province (in Chinese), Beijing: Geological Publishing House, 1991, 1—662.

(Received December 2, 2003; accepted February 7, 2004)