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SHRIMP dating of the Bangong Lake SSZ-type ophiolite: Constraints on the closure time of ocean in the Bangong Lake-Nujiang River, northwestern Tibet

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The Bangong Lake ophiolite is located in the westernmost part of the Bangong Lake-Nujiang River suture zone. It is a tectonic mélange consisting of numerous individual blocks of peridotite, pillowed and massive lavas and mafic dykes with SSZ-type ophiolitic geochemical affinity formed at the end of a Wilson circle. The SHRIMP U-Pb ages of the co-magmatic zircon domains from one gabbroic dyke (Sample 01Y-155) range from 162.5±8.6 Ma to 177.1±1.4 Ma with an average of 167.0±1.4 Ma (n = 12, MSWD = 1.2), suggesting that the subduction of the Bangong Lake Neo-Tethyan Ocean started before the Middle Jurassic. It is inferred that the tectonic transform from spreading to subduction of the Neo-Tethyan Ocean began before the Middle Jurassic in the Bangong Lake area.

SSZ-type ophiolite, gabbro, zircon, SHRIMP, Bangong Lake, Tibet

The Bangong Lake-Nujiang River suture zone (BNSZ) is an important tectonic boundary between the Lhasa and Qiangtang blocks[1−3], representing a significant, yet poorly understood early tectonic evolution of northern Tibet. There are several markedly contrasting views about the tectonic background and significance of the BNSZ ophiolites. Wang et al.[4] suggested that the Bangong Lake ophiolite formed in the Middle and Late Jurassic time in light of radiolarians from the inter-pillow lava cherts. Based on the whole-rock Sm-Nd age of gabbros from the Shemalagou ophiolite in the middle of the BNSZ, Qiu et al.[5] inferred that the Bangong Lake Neo-Tethys opened before the early Jurassic time, while Ren et al.[3], according to the 1:250 thousand regional mapping, suggested that the BNSZ and Yarlung Zangbo River suture zone both represent the Late Permian-Early Triassic Neo-Tethys consistent with the typical Neo-Tethys concept defined early by Suess. The Upper Jurassic lying unconformably on the ophiolite blocks indicates that the Bangong Lake Neo-Tethys was closed at some time earlier than the Early Cretaceous, while in the upper reaches of Nujiang River, the Middle Jurassic strata lying unconformably on the ophiolite blocks suggest that the Neo-Tethys close time in the upper reaches of Nujiang River was earlier than in the Bangong Lake area[6]. The poor understanding of the formation background of the ophiolite is likely a major reason causing the above mentioned controversy. For example, it remains unknown whether the pillow lavas with radiolarian cherts and the dating gabbros formed in the middle ocean ridge or in the suprasubduction zone tectonic settings. Also, it is unclear whether the ages of them represent the spreading or subduction time of the Neo-Tethys. Therefore, the poor recognition of ophiolite has hindered the further understanding of the early tectonic evolution of Tibet.

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Recently, the recognition of the SSZ-type ophiolite in the Bangong Lake invites further determination of its formation age. This paper presents the first SHRIMP dating of the gabbro dyke from the Bangong Lake SSZ-type ophiolite in the westernmost part of the Bangong Lake-Nujiang River suture zone and discusses the tectonic transition from spreading to subduction of the Neo-Tethys and lower limit of the open timing of the Neo-Tethys in the Bangong Lake area.

1 Geological setting

The Bangong Lake ophiolite section in the western most part of the Bangong Lake-Nujiang River ophiolite zone is located to the south of the Bangong Lake and about 10 km north of Rutong Town. Being over 2000 km long in Tibet, it extends westward to Kashmir and southeastward beyond Tibet along the Nujiang River. It consists of a number of individual blocks of mantle peridotites, gabbro, diabase dykes, pillowed and massive lavas orienting in an E-W direction, surrounded by Cretaceous sedimentary rocks (Figure 1). The individual ophiolite blocks contain many autoclastic and exotic blocks and the original sequence is rarely preserved. The ophiolite blocks tectonically emplaced into the Jurassic sandstone, con-glomerate and shale. The Jurassic strata are intercalated with some Permian exotic limestone blocks, forming an olistostrome. The Bangong Lake ophiolite, olistostrome and other rocks in this area form the Bangong Lake ophiolite mélange. According to the characteristics of petrology, mineralogy and geochemistry of the mantle peridotites, gabbro, diabase dykes and lavas, a suite SSZ-type ophiolite is recognized from the mélange, which is composed of massive high-Cr$^{\#}$ spinel harzburgite, gabbro, diabase dykes, pillow basalts, basaltic andesite and boninite series volcanic rocks[7−9].

The gabbro (01Y-155) for ophiolite age dating intrudes the high-Cr$^{\#}$ spinel harzburgite as an individual, and subvertical body of about 1 m wide (Figure 2). It is medium- to coarse-grained, greenish gray rocks chiefly composed of about 50 vol.% chlorite replaced part pyroxenes, 45 vol.% saussuritized plagioclase and trace amounts of magnetite. It is basalt composed of SiO_2 content 49.3 wt.%, MgO content 9.01 wt.% and total iron content 10.44 wt.%. Alumina (14.07 wt.%) and TiO_2 (0.81 wt.%) contents of the gabbro generally fall in the field of the pillow basalts (12.4—15.5 and 0.8 wt.%—1.6 wt.%, respectively), whereas K_2O is over 1.0 wt.% higher than that of the pillow lavas (0.09 wt.%—0.25 wt.%), suggesting significant alteration. Chondrite-normalized rare earth element (REE) pattern of the gabbro is nearly flat, with a very slight LREE enrichment, showing a weak positive Eu anomaly (δEu=1.18)[9]. In the N-MORB-normalized trace element pattern (Figure 3(a)), the gabbro shows a stronger depletion in all elements from Ta to Cr with a lower Zr/Hf ratio (27) than that of N-MORB (36.1) and generally a stronger enrichment in Sr, K, Rb, Ba, and Th than other lavas, indicating that it originated from a depleted source[9]. In the Th-Hf-Ta discrimination diagram (Figure 3(b)), the gabbro plots in the field of island arc tholeiitic basalts, suggesting it formed in the suprasubduction zone environment.

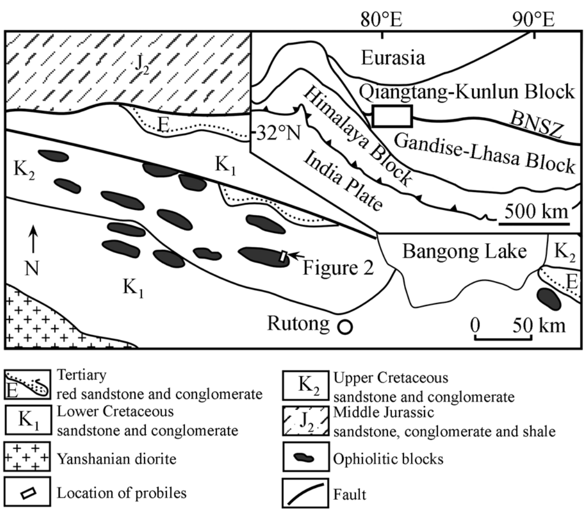

Figure 1 Structural framework of Tibet and adjacent India, showing position of the Bangong Lake ophiolites.

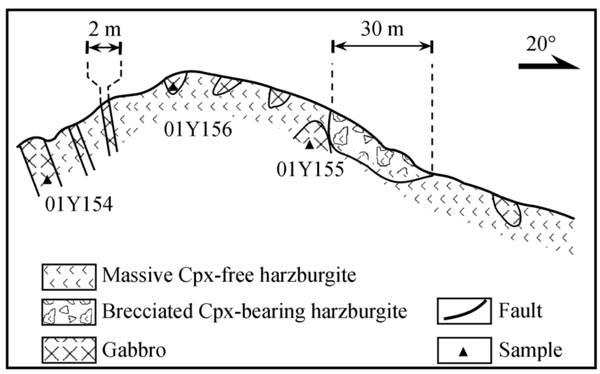

Figure 2 Cross section through the Bangong Lake ophiolite showing the sample locations.

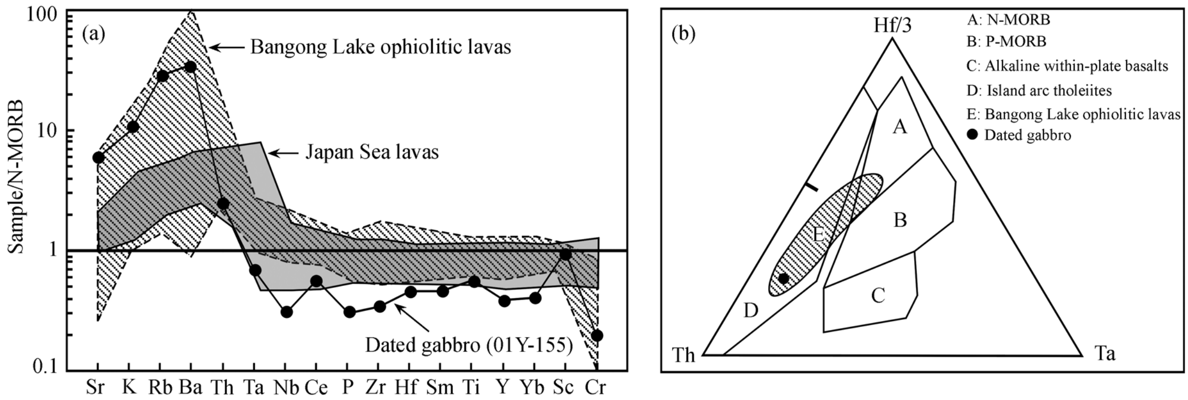

Figure 3 (a) Trace element concentrations, normalized to the composition of N-MORB, for the Bangong Lake ophiolitic lavas (data of Bangong Lake ophiolite from ref. [9], normalized N-MORB data from ref. [10], data of Japan Sea lavas from ref.[11]); (b) tectonic discrimination diagram of Hf/3-Th-Ta (after ref. [12]).

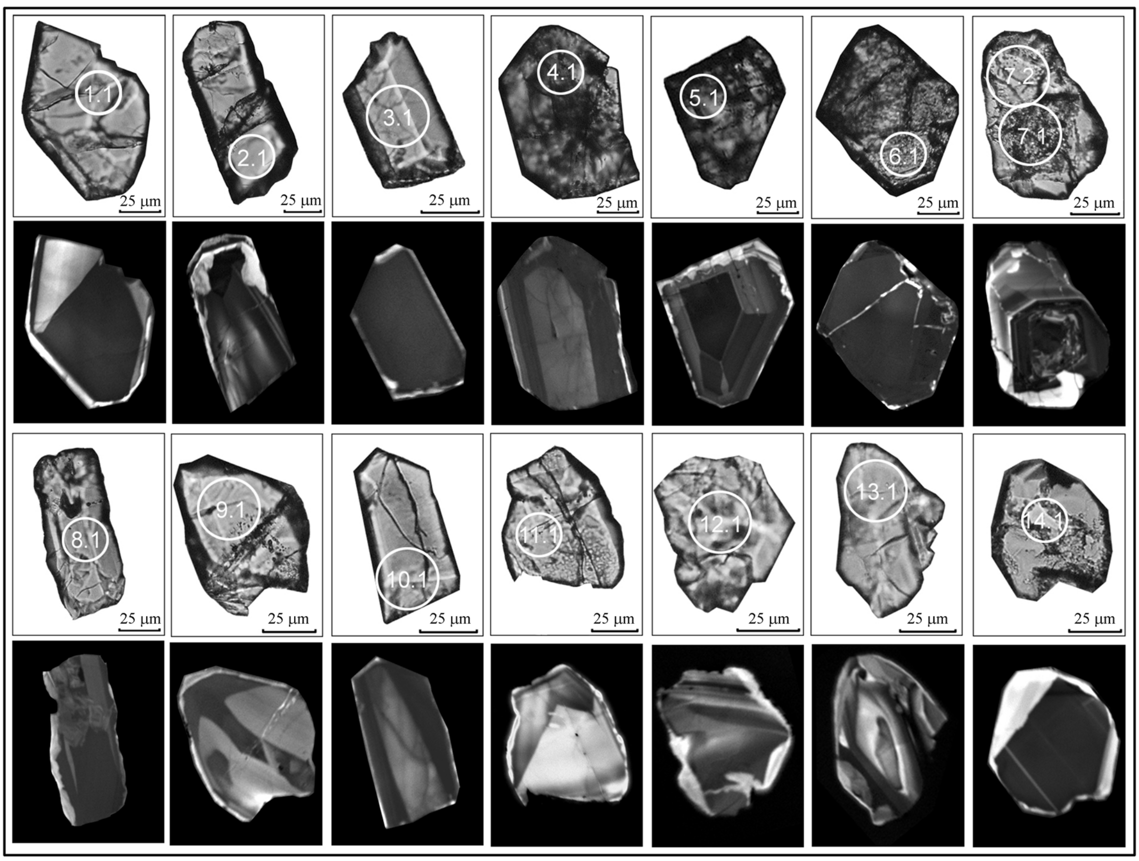

Figure 4 Polarized light (PL) and cathodoluminescence (CL) images of zircons in the gabbro from the Bangong Lake ophiolite in Tibet.

2 SHRIMP dating results

In this study, zircons separated from one gabbroic dyke (Sample 01Y-155) intruding the massive harzburgite were dated using a SHRIMP II machine at the Beijing SHRIMP Center. Cathodoluminescence (CL) images and polarized (PL) pictures (Figure 4) were collected from the zircons before analyses. Uncertainties in ages are quoted at the 95% confidence level (2σ) and spot diameter was 30 μm. Common Pb corrections were made using measured ^{204}Pb (Table 1).

The SHRIMP II analyses followed established methods[13−15]. The calibration standard is Sri Lankan gem zircon standard (SL13), and the internal standard is the

Table 1 SHRIMP U-Pb data of zircons from gabbro (sample 01Y155) in the Bangong Lake SSZ-type ophiolite a)

Spot	f^{206}Pb (%)	U (10^{-6})	Th (10^{-6})	Th/U	^{207}Pb/^{206}Pb	Error (%)	^{207}Pb/^{235}U	Error (%)	^{206}Pb/^{238}U	Error (%)	^{206}Pb/^{238}U age (Ma)	Error (1σ)
1.1	0.14	3242	7671	2.37	0.0505	1.6	0.186	1.7	0.0268	0.6	170.4	1.0
2.1	1.21	1148	776	0.68	0.0458	8.2	0.167	8.3	0.0264	1.4	168.1	2.3
3.1	0.42	2401	3931	1.64	0.0497	2.9	0.180	3.0	0.0262	0.6	167.0	1.1
4.1	0.67	2376	6371	2.68	0.0481	3.6	0.174	3.7	0.0262	0.7	166.7	1.1
5.1	0.26	4151	2546	0.61	0.0488	2.5	0.178	2.6	0.0265	0.6	168.4	1.0
6.1	0.15	5492	3269	0.60	0.0498	1.8	0.177	1.9	0.0258	0.6	164.0	1.0
7.1	0.56	4785	2498	0.52	0.0489	2.4	0.159	2.9	0.0236	1.6	150.5	2.4
7.2	0.66	2680	952	0.36	0.0485	4.8	0.149	6.2	0.0222	3.9	141.7	5.5
8.1	0.42	2721	2737	1.01	0.0492	2.7	0.180	2.8	0.0265	0.7	168.9	1.1
9.1	0.41	1762	1702	0.97	0.0515	4.1	0.198	4.2	0.0278	0.8	177.1	1.4
10.1	0.43	2514	4278	1.70	0.0534	3.6	0.188	6.4	0.0255	5.3	162.5	8.6
11.1	1.20	976	863	0.88	0.0445	11.9	0.160	12.0	0.0261	1.0	166.3	1.7
12.1	0.25	1131	465	0.41	0.0581	3.0	0.210	3.1	0.0262	0.9	166.6	1.5
13.1	0.43	1240	1050	0.85	0.0525	3.9	0.192	4.0	0.0266	0.9	169.0	1.5
14.1	0.00	2406	2175	0.90	0.0526	1.7	0.187	1.8	0.0258	0.6	164.0	1.0

a) f^{206}Pb (%): common ^{206}Pb content.

Australian National University zircon standard TEMORA 1[13]. The CL and PL images show that most of the recovered zircons are euhedral and elongated, with no distinct cores or rims (except No.7) and no other mineral inclusions. They typically have good oscillatory zoning, and characteristic of magmatic zircons. The Th/U ratios of the zircons from the gabbro vary from 0.53 to 2.76, >0.23 (Table 1), and are also typical of magmatic origin[16], in agreement with the CL and PL images.

Sixteen analyses of the zircons yielded ^{206}Pb/^{238}U ages ranging from 162.5 ± 8.6 Ma to 177.1 ± 1.4 Ma with a weighted mean ^{206}Pb/^{238}U age of 167.0 ± 1.4 Ma (n = 12, MSWD = 1.2). The No.7 zircon CL image study shows that the SHRIMP spot overlaps an inherited older core, thereby giving a 'mixed age' (150.5 ± 2.4 Ma). All the data points are nearly concordant in the ^{207}Pb/^{235}U vs. ^{206}Pb/^{238}U diagram (Figure 5). Therefore, the best estimated age of the gabbro is 167.0 ± 1.4 Ma.

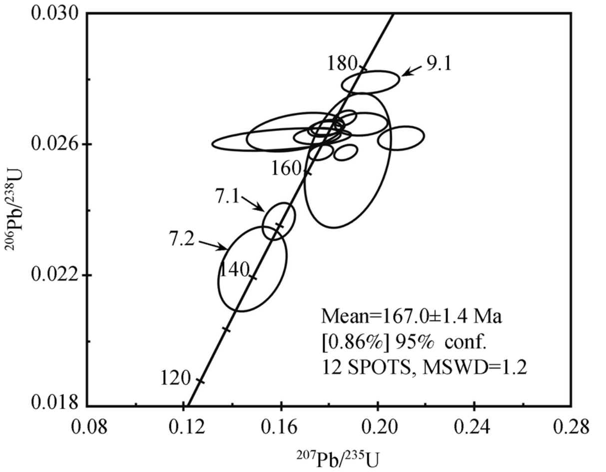

Figure 5 The concordia diagram showing ^{206}Pb/^{238}U-^{207}Pb/^{235}U ratios and mean weighted ^{206}Pb/^{238}U age for zircon grains in the gabbro from the Bangong Lake ophiolite.

3 Discussion

The SSZ-type ophiolite formed in the convergent boundary of tectonic plates during the closure of an ocean, so the age of this kind ophiolite directly indicates the time of tectonic transformation from spreading to subduction of ocean[17−20]. In the Tibet Plateau, the Yarlung Zangbo River in southern Tibet and the Bangong Lake-Nujiang River in northern Tibet are the well-preserved Neo-Tethyan ophiolitic belts[21]. Although there is a consensus on the petrogenesis and emplaced time of the Yarlung Zangbo River ophiolites, most researchers have been agreed that the Yarlung Zangbo River ophiolite formed in the suprasubduction zone environment [17,19,22−24], and was emplaced on the south margin of the Lhasa block during 80−90 Ma[19]. There exits a controversy over the age of the Yarlung Zangbo River ophiolite considered to have formed in the SSZ environment. Previous studies show that the intra-ocean subduction took place in the Middle Cretaceous time[25], but recent SHRIMP dating results indicate that the Yarlung Zangbo River ophiolite was likely formed during Middle Jurassic time, suggesting that the subduction in the Yarlung Zangbo ocean started at least from the Middle Jurassic[26].

The gabbro (sample 01Y-155) used for dating the age of the Bangong Lake ophiolite intrudes the high Cr# (>0.60) spinel harzburgite, which experienced extensive serpentinization with orthopyroxene replaced by bastite and olivine by serpentine and secondary magnetite. Disseminated spinel is reddish-brown in color, and many grains are rimmed with magnetite. The orthopyroxene grains have lobate grain boundaries, resulting in an "embayment texture", which is interpreted as the result of resorption associated with incongruent melting or dissolution of orthopyroxene. Based on the relative percentages of bastite pseudomorphs and mesh-textured groundmass, we estimate that these rocks originally contained about 85 vol.% olivine, 13 vol.% orthopyroxene, and 2 vol.% disseminated spinel. The lower CaO and Al_2O_3 contents of the harzburgite reflect the high degree partial melting of the convecting upper mantle, and the U-shaped Chondrite-Normalized REE patterns are interpreted as the effect of fluids in the suprasubduction zone. Spinels in the harzburgite have high $Cr^{\#}$ (0.69−0.74) and low $Mg^{\#}$ (50.6−58.4). Dick and Bullen (1984) suggested that chromian spinels with high $Cr^{\#}$ (>0.60) are restricted to volcanic arcs, stratiform complexes and oceanic plateau basalts. Thus, the harzburgites probably formed in a suprasubduction zone environment[8,17,18,27−30]. The occurrence and the IAT geochemical features of the gabbro (Sample 01Y-155) indicate that it formed originally in an intra-oceanic subduction zone, and that a fragment of this oceanic lithosphere was incorporated in the overlying mantle wedge. Therefore, its age represents the time of intra-oceanic subduction. As mentioned before, the U-Pb age of co-genetic zircons separated from the gabbro (Sample 01Y-155) ranges from 162.5 ± 8.6 Ma to 177.1 ± 1.4 Ma, indicating that the tectonic transition from spreading to intra-oceanic subduction of the Neo-Tethys started at the Middle Jurassic.

If it is true that the intra-ocean subduction of the Yarlung Zangbo River Neo-Tethys occurred during the Middle Cretaceous, and the intra-ocean subduction of the Bangong Lake Neo-Tethys was older than that of the Yarlungzangbo River Neo-Tethys. However, a recent Sm-Nd isochronal age (177 Ma) of the gabbros from the Luobusa SSZ-type ophiolite[31] and the latest U-Pb age (162 Ma) of the Zedang Island arc west of the Luobusa ophiolite suggest that the intra-ocean subduction of the Yarlung Zangbo River Neo-Tethys began likely from 160−170 Ma[21], being consistent with the older subduction record other than the Sangri Group from the Yarlung Zangbo River ophiolitic melange[26].

Therefore, we infer that the tectonic transition from spreading to subduction of the Yarlung Zangbo River and the Bangong Lake-Nujiang River Neo-Tethys commenced simultaneously from the Middle Jurassic.

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