Solonker ophiolite in Inner Mongolia, China: A late Permian continental margin-type ophiolite

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ABSTRACT

The Solonker ophiolite is exposed along the border between Mongolia and China within the Solonker zone, the southeastern Central Asian Orogenic Belt (CAOB), and it is composed dominantly of serpentinitized peridotite with subordinate gabbro, basaltic lava, radiolarian-bearing siliceous rocks, and minor plagiogranite. Meanwhile, layered mafic-ultramafic cumulates are not ubiquitous. In this study, zircon grains from two gabbros and a plagiogranite yield $^{206}\text{Pb}/^{238}\text{U}$ ages of 259 ± 6 Ma, 257 ± 3 Ma and 263 ± 1 Ma. These data were interpreted to represent the formation age of the Solonker ophiolite. The studied gabbros and basalts have a tholeiitic composition, showing a MORB affinity. They are also characterized by enrichment of Pb and depletion of Nb relative to La and Th. Furthermore, the studied gabbros contain inherited zircon grains and display a large range of zircon Hf isotopes ($\varepsilon\text{Hf}(t) = -5.27$ to $+10.19$). These

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features imply that crustal contamination played an important role in the generation of these mafic rocks. Major elements derived from the radiolarian-bearing siliceous rocks suggest a continental margin setting. This is confirmed by rock association. Terrigenous rocks (sandstones and siltstones) interstratified with siliceous rocks. U-Pb dating of detrital zircon grains in sandstones from both the northern and southern sides of the Solonker ophiolite belt, along with published data, reveals that the Late Carboniferous-Early Permian strata in fault contact with the Solonker ophiolite was deposited above Early Paleozoic orogens. The lines of petrological, geochemical, geochronological, and isotopic evidence led us to propose that the Solonker ophiolite is a Late Permian continental margin-type body formed during the early stages of opening of an ocean basin, following rifting and break-up of the Early Paleozoic orogens. Accordingly, the Permian Solonker zone is characterized by an intra-continental extensional setting.

1. Introduction

Ophiolites represent fragments of the upper mantle and oceanic crust (Coleman, 1977; Nicolas, 1989), and as such preserve records of the evolution and destruction of ancient oceanic lithosphere (Dilek, 2006; Dilek and Furnes, 2011; Furnes et al., 2015). They can provide key evidence to understand the evolution of both accretionary and collisional orogenic belts (Dilek, 2006; Furnes et al., 2015; Miao et al., 2008). Furthermore, ophiolites preserve varied structural architectures, chemical fingerprints, and related evolutionary paths, indicating different tectonic origins (Dilek, 2003). According to a recent study (Dilek and Furnes, 2011, 2014), ophiolites can be divided

into subduction-unrelated and subduction-related categories. The subduction-unrelated ophiolites can further be subdivided into continental margin (CM)-type, mid-ocean ridge (MOR)-type, and plume (P)-type ophiolites. In particular, the CM-type ophiolites correspond to the Ligurian-type ophiolite, which were formed in the early stages of an ocean basin following the initiation of continental breakup. The subduction-related ophiolites include supra-subduction zone (SSZ)-type and volcanic arc (VA)-type. These five types of ophiolite are thus indicative of different tectonic settings and can be identified through their internal structures, geochemical signatures, and regional tectonics (Dilek and Furnes, 2011; Furnes et al., 2015).

The Central Asian Orogenic Belt (CAOB) is a giant accretionary orogen between the Siberian Craton (SC) to the north and the Tarim and North China Cratons (NCC) to the south (Fig. 1a; Şengör et al., 1993; Badarch et al., 2002; Jahn et al., 2004; Windley et al., 2007; Xiao et al., 2009). It was mainly formed by the subduction of the Paleo-Asian Ocean (PAO) and the subsequent amalgamation of terranes of different types and derivation (Coleman, 1994; Heubeck, 2001; Badarch et al., 2002; Xiao et al., 2003).

The PAO between the SC and NCC was first introduced by Zonenshain et al. (1990). Tectonic evolution of the PAO has long been a subject of extensive studies (Tang and Yan, 1993; Xiao et al., 2003, 2009; Miao et al., 2008; Jian et al., 2008, 2010; Zhang et al., 2011; Xu et al., 2013; Zhao et al., 2013), but the controversy concerning the timing and the exact location of its final closure has lasted over several decades. Some proposed that the PAO had closed by the end of the Devonian (Zhang and Tang,

1989; Tang, 1990; Zhao et al., 2013). Recently, Xu et al. (2013) improved this model and further proposed that there was an independent micro-continental block within the PAO, i.e., the Hunshandake block, which approaches the northern margin of the NCC. The PAO was thus separated into the southern and northern branches. The southern branch closed during the Late Silurian, whereas the northern branch closed during the Late Devonian, resulting in the formation of the Southern and Northern orogenic belts, respectively (Xu et al., 2013). Following these orogenic events, the southeastern part of the CAOB underwent widespread continental rifting during the Late Paleozoic (Zhang and Tang, 1989; Tang, 1990; Chu et al., 2013; Shao et al., 2014), characterized by Early Permian alkaline A-type granitoids (Shi et al., 2004; Jahn et al., 2009), bimodal volcanic rocks (Zhang and Li, 1997; Zhu et al., 2001; Zhang et al., 2008), and extensional sedimentary basins (Tang 1990; Luo et al., 2015).

However, Jian et al. (2008) suggested that both the Southern and Northern orogenic belts were produced by the collision of continents and island arcs during the Late Silurian when the PAO still existed between these two orogenic belts. During the Early Permian, the PAO subducted beneath the NCC resulting in continental arc and ridge-trench collision, followed by the final closure of the PAO during the Late Permian–Early Triassic (Jian et al., 2008, 2010). Nevertheless, Xiao et al. (2003, 2009) argued that the double subduction of the PAO crust beneath the southern margin of the SC and the northern margin of the NCC lasted for the entire Paleozoic until collision occurred between the two opposing active continental margins. This led to the formation of the Solonker suture during the Late Permian (Xiao et al., 2003). Based on

SHRIMP zircon U-Pb ages and the geochemical features of the Late Paleozoic ultramafic-mafic rocks and granitic intrusions, Zhang et al. (2007, 2009) and Miao et al. (2008) also suggested that the final closure of the PAO along the Solonker suture occurred in the late Permian.

The Solonker zone (SZ) between the Southern and Northern orogenic belts, extending from Solonker, via Mandula, to Linxi, is thus a key area of study needed to clarify the above-mentioned debates. Nevertheless, the evolution of the SZ is still poorly understood, which is largely attributed to the lack of detailed studies on the ophiolite suites within this zone. An ophiolite belt, named the Solonker ophiolite (BGMR, 1982; Jian et al., 2008), is well preserved along the border between Mongolia and China in the western part of the SZ. In this paper, we present new detailed field observations, geochemical, and zircon U-Pb dating results for the dominant lithologies (e.g., basalt and gabbro) from the Solonker ophiolite. Based on these new data, we discuss the age, nature, and tectonic setting of the Solonker ophiolite and provide important clues to unravel the tectonic evolution of the SZ and the timing of the final closure of the PAO.

2. Geologic setting

2.1 Geologic outline

From north to south, five units can be identified in the southeastern CAOB: the Xing'an-Airgin block (XAB) (South Mongolian microcontinent on the Mongolia side), the Northern orogenic belt (NOB), the Songliao-Hunshandake block (SHB), the Southern orogenic belt (SOB), and the northern margin of the NCC (Xu et al., 2013,

2014, 2015; Fig. 1b). The western extension of the SOB and the NOB converge in the SZ.

2.1.1 Northern orogenic belt (NOB)

The NOB includes four sub-units from north to south: an arc-pluton belt, *mélange*, foreland molasse basin, and fold belt, which represent a northern subduction–collision system formed during 500–380 Ma between the SHB and XAB blocks (Xu et al., 2013). The arc-pluton belt, extending from Xilinhot, via Bayanbaolidao, to the north of the Solonker area, is composed of cumulate gabbros, gabbro-diorites, quartz diorites, tonalites, and granites, representing a magmatic arc formed from 500–420 Ma (Jian et al., 2008; Xu et al., 2013, 2015). The *mélange* with a high pressure metamorphic age of 383 Ma (Xu et al., 2001) occurs from Honger, Naomuhunni, to Airgin Sum, marking the suture line of the NOB (Xu et al., 2013). Upper Devonian molassic deposits unconformably overlie the *mélange* (Zhang et al., 2010). The fold belt, occurring to the south of the *mélange* and the molasse basin, represents the northward-subducted passive margin of the SHB during the Early Paleozoic.

2.1.2 Southern orogenic belt (SOB)

The SOB, extending from Ondor Sum, via Bater, to the south of the Solonker area, represents a southern subduction–collision system between the NCC and SHB blocks during 500–440 Ma and includes two sub-units from north to south: the Ondor Sum subduction–accretion complex and an island arc belt (Jian et al., 2008; Xu et al., 2013). The Ondor Sum subduction–accretion complex consists of a subduction complex and an ophiolite, representing an Early Paleozoic accretionary wedge related to the

southward subduction (Xiao et al., 2003; Jian et al., 2008). The island arc belt is made of volcanic rocks and plutons with an age of 425-488 Ma (Miao et al., 2007; Jian et al., 2008; Xu et al., 2013). Silurian flysch and the lower Devonian molasse deposits unconformably overly the island arc belt (Zhang et al., 2010; Xu et al., 2013).

2.1.3 Songliao-Hunshandake block (SHB)

The SHB occurs between the NOB and the SOB, and its western extension disappears in the SZ. The basement of the SHB is composed of Paleo- and Neo-Proterozoic granitic rocks, which has been well documented in the eastern part of the block (Xu et al., 2013, 2015). For example, a SHRIMP U-Pb zircon age of 1839 ± 7 Ma (Wang et al., 2006) for a granodiorite and an LA-ICPMS U-Pb zircon age of 1808 ± 21 Ma for a meta-gabbro (Pei et al., 2007) have been reported in the southeastern margin of this block. Late Paleozoic cover of this block is comprised of Carboniferous-Permian limestone, conglomerate, and sandstone (IMBGMR, 1991). The Carboniferous strata have been interpreted to be deposited in an inland sea after the Early Paleozoic orogenic events (Zhao et al., 2015), whereas a predominant shallow marine environment was proposed for the Permian strata (IMBGMR, 1991).

2.2 Stratigraphy of the Solonker-Mandula area

Carboniferous-Permian strata exposed in the Solonker-Mandula area along the Mongolia/China border are comprised of, from bottom to top, Late Carboniferous carbonate, Late Carboniferous-Early Permian carbonate/clastic rocks, Early Permian bimodal volcanic rocks and Hugierte-Chaghanhadamiao volcanic-plutonic belt, Middle Permian carbonate/clastic rocks, and Late Permian turbidite (Figs. 2 and 3).

The Late Carboniferous carbonates assigned as the Amushan Formation (Shi, 2013) were interpreted to be formed in an inland sea (Zhao et al., 2015), and consist of bioclastic limestone and sparite with fusulinids and crinoids. This succession has been thrust onto the Late Carboniferous-Early Permian carbonate-clastic rocks caused by top-to-north thrusting (Fig. 3a). The Late Carboniferous-Early Permian carbonate-clastic rocks are mainly composed of interlayered fuchsia sandstone, siltstone, and limestone (Fig. 3b). They show features of normal sedimentary sequences with parallel bedding and are supposed to be marine-terrigenous deposits (IMBGMR, 1991). The repetitive sandstone and siltstone layers have a uniform southeastern dip.

The Early Permian bimodal volcanic rocks distributed in the northernmost part of the study area are mainly composed of rhyolitic and basaltic lavas. They are defined as the Dashizhai Formation with eruption ages of ~280 Ma (Wang et al., 2005; Zhang et al., 2008). Tectonically sandwiched by the Late Carboniferous-Early Permian strata, the Hugierte-Chaganhadamiao volcanic-plutonic belt has eruption ages of 273-288 Ma (Jian et al., 2010; Chen et al., 2012), which is consistent with the age of the Dashizhai Formation. The volcanic rocks are mainly composed of pillow and massive basalt, dacite, and rhyolite with minor andesite (Fig. 3c). The plutonic rocks include gabbro, diorite, and plagiogranite.

The Middle Permian clastic-carbonate rocks assigned as the Zhesi Formation (Wang et al., 2005) are mainly composed of conglomerate and pebbly sandstone with subordinate fossil-bearing limestone (Fig. 3d). Overlying the Zhesi Formation, the Late

Permian turbidite (Shi, 2013) is characterized by inter-layered mudstone, siltstone, and sandstone with variable thickness, similar to the Bouma sequence that commonly occurs in several outcrops (Fig. 3e). Olistostromes are developed at the bottom of the turbidite sequence. The presence of serpentinites (Fig. 3f) and siliceous rocks occurring as olistoliths in the matrix of sandstones and siltstones yields evidence for erosion of the Solonker ophiolite.

3. Solonker ophiolite

The E-W trending Solonker ophiolite is located in the western part of the SZ along the China/Mongolia border (Figs. 1b and 2). Based on our field observations, the Solonker ophiolite is dominated by peridotite, along with small volumes of gabbro, basalt, and siliceous rock with minor plagiogranite.

The extensively serpentinized peridotites are characterized by the development of tectonic breccias consisting of serpentinite cross-cut by calcite or dolomite veins at its top (Fig. 4a). The peridotite consists of serpentine, clinopyroxene, orthopyroxene, and some relict olivine (Fig. 5a), which suggests that the peridotite is lherzolite. The peridotites were intruded by gabbros in the western segment of the Solonker ophiolite on the Mongolian side (Jian et al., 2008).

In geologic section (I) of the mafic rocks in the Wuzhuershaobute area (Fig. 6a), the lower part mainly consists of a plutonic sequence with minor basalts. The plutonic sequence is composed of gabbros and rare diabases without sheeted dike complexes. In addition, gabbroic rocks are mainly composed of isotropic gabbros with rare cumulate gabbros (Fig. 4b). The gabbros mainly consist of clinopyroxene, plagioclase, and

opaque minerals, exhibiting granular texture (Fig. 5b). They most likely experienced greenschist-facies metamorphism as exemplified by the presence of actinolite and chlorite.

The middle part of the section consists of interlayered basalts and siliceous rocks, whereas the upper part is mainly composed of basalts that were intruded by gabbros (Fig. 4d) and plagiogranite (Fig. 6a), and covered by siliceous rocks. The basalts occur as pillow lava and as massive flows (Fig. 4c). They are non-amygdaloidal and predominantly aphyric or slightly phyric and have also experienced greenschist-facies metamorphism as exemplified by the presence of actinolite and chlorite (Fig. 5c). The plagiogranite is medium-grained and hypidiomorphic and mainly consist of plagioclase and quartz (Fig. 5d).

In geologic section (II) of siliceous rocks near Bayanaobao (Fig. 6b), a few intercalations of sandstone and siltstone are observed (Figs. 4e-f). Radiolarians *Pseudoalbaillella* were also found in the siliceous rocks (Wang et al., 2005). Our field observations show that the siliceous rocks directly overlie the peridotite (Fig. 4g). As observed in thin sections, the siliceous rocks have a relatively high argillaceous component compared with typical pelagic siliceous rocks (Fig. 5e), indicating a proximal continental margin depositional setting.

On the southern side, the Late Carboniferous-Early Permian strata are in structural contact with the ophiolites through a high-angle south-dipping fault. The kinematic indicators along this fault show significant features of south to north thrusting (Fig. 4h). On the northern side, the ophiolite fragments are also in fault contact with the Late

Carboniferous-Early Permian strata.

4. Sample collection

Four basalt, five gabbro, and five siliceous rock samples were collected for geochemical analyses (Fig. 6). Two gabbro samples (130808-08 and SGZ-3) were selected for U-Pb zircon dating and Hf isotopic study (Fig. 2). A plagiogranite sample 141005-05 was also collected for U-Pb zircon dating (Fig. 6). A sandstone (140419-04) from the sedimentary sequence to the north of the ophiolite belt and a sandstone (141005-07) from the sedimentary sequence to the south of the ophiolite belt (Figs. 2 and 6) were collected for U-Pb zircon dating to constrain the temporal relationship between the Solonker ophiolite and its surrounding strata.

Zircons were separated from the gabbro, plagiogranite and sandstone samples through standard heavy-liquid and magnetic techniques, and handpicked under a binocular microscope at the Chengxin Geology Service Co. Ltd, Langfang, Hebei Province, China. Cathodoluminescence (CL) imaging was performed using a FEI Quanta 200F scanning electron microscope at the Electron Microscopy Laboratory of Peking University to reveal the internal textures of zircons.

Zircon U-Pb dating for gabbro sample 130808-08 was conducted using the Cameca IMS-1280 SIMS at the Institute of Geology and Geophysics, Chinese Academy of Sciences. Detailed analytical procedures are described in Li et al. (2009). The O-primary ion beam with an intensity of ca. 10 nA was accelerated at -13 kV. The ellipsoidal spot is about 20 μm $\times$ 30 μm in size. Calibration of Pb/U ratios is relative to the standard zircon TEMORA2 (417 Ma) (Black et al., 2004) based on an observed

linear relationship between $\ln(^{206}\text{Pb}/^{238}\text{U})$ and $\ln(^{238}\text{U}^{16}\text{O}/^{238}\text{U})$ (Whitehouse et al., 1997). U and Th concentrations of unknowns are determined relative to the standard zircon 91500 with Th and U concentrations of ca. 29 and 81 ppm respectively (Wiedenbeck et al., 1995). Measured compositions were corrected for common Pb using ^{204}Pb . An average of present-day crustal composition (Stacey et al., 1975) is used for the common Pb. Uncertainties on individual analyses are reported at 1σ level; mean ages for pooled U-Pb analyses are quoted with 95% confidence interval. Data reduction was carried out using the Isoplot/Ex v. 2.49 program.

Zircon U-Pb dating for gabbro sample SGZ-3, plagiogranite sample 141005-05 and sandstone samples were determined by Laser ablation–inductively coupled plasma-mass spectrometer (LA–ICP-MS) at the Key Laboratory of Orogen and Crust Evolution, Peking University. The instrument couples a quadrupole ICP-MS (Agilent 7500c) and 193-nm ArF Excimer laser (COMPexPro 102, Coherent, DE) with the automatic positioning system. Calibrations for the zircon analyses were carried out using NIST 610 glass as an external standard and Si as internal standard. U–Pb isotope fractionation effects were corrected using zircon Plesovice (337 Ma) as external standard. Zircon standard 91500 is also used as a secondary standard to supervise the deviation of age measurement/calculation. Isotopic ratios and element concentrations of zircons were calculated using GLITTER (version 4.4.2, Macquarie University). Concordia ages and diagrams were obtained using Isoplot/Ex (3.0) (Ludwig, 2003). The common lead was corrected using LA-ICP-MS Common Lead Correction (version 3.15), following the method of Andersen (2002). The analytical data are presented on

U–Pb Concordia diagrams with 1σ errors. The mean ages are weighted means at 95% confidence levels (Ludwig, 2003).

In situ zircon Hf isotope analyses were conducted using a Neptune Plus MC-ICP-MS (Thermo Fisher Scientific, Germany) in combination with a Geolas 2005 excimer ArF laser ablation system (Lambda Physik, Göttingen, Germany) that was hosted at the state Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences in Wuhan. A “wire” signal smoothing device is included in this laser ablation system, by which smooth signals are produced even at very low laser repetition rates down to 1 Hz (Hu et al., 2012). The directly obtained β_{Yb} value from the zircon sample itself was applied in real-time in this study. The $^{179}\text{Hf}/^{177}\text{Hf}$ and $^{173}\text{Yb}/^{171}\text{Yb}$ ratios were used to calculate the mass bias of Hf (β_{Hf}) and Yb (β_{Yb}), which were normalized to $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$ and $^{173}\text{Yb}/^{171}\text{Yb} = 1.132685$ (Fisher et al., 2014) using an exponential correction for mass bias. Interference of ^{176}Yb on ^{176}Hf was corrected by measuring the interference-free ^{173}Yb isotope and using $^{176}\text{Yb}/^{173}\text{Yb} = 0.79639$ (Fisher et al., 2014) to calculate $^{176}\text{Yb}/^{177}\text{Hf}$. Similarly, the relatively minor interference of ^{176}Lu on ^{176}Hf was corrected by measuring the intensity of the interference-free ^{175}Lu isotope and using the recommended $^{176}\text{Lu}/^{175}\text{Lu} = 0.02656$ (Blichert-Toft et al., 1997) to calculate $^{176}\text{Lu}/^{177}\text{Hf}$. We used the mass bias of Yb (β_{Yb}) to calculate the mass fractionation of Lu because of their similar physicochemical properties. Off-line selection and integration of analytic signals, and mass bias calibrations were performed using ICPMSDataCal.

Major element analysis for siliceous rock samples was performed on an X-ray

fluorescence spectrometer (XRF) at Key laboratory of Orogenic Belts and Crustal Evolution, Peking University, Ministry of Education, China. Analytical precision (relative standard deviation) is <1% for the major elements. Major, trace and rare earth element analyses for basalt and gabbro samples were measured by ICP-emission spectrometry and inductively coupled plasma mass spectrometry (ICP-MS) at Acme Analytical Laboratories in Vancouver, Canada. Major elements were analyzed by the ICP-emission spectrometry method with detection limit 0.01%. Loss on ignition (LOI) was determined by placing 1 g of samples in the furnace at 1000 °C for several hours before being cooled in a desiccator and reweighing. Trace and rare earth elements were analyzed by ICP-MS. The detection limit was around 0.1 ppm for trace element, and around 0.01 ppm for rare earth element. The analytical data are listed in Tables 5 and 6.

5. Results

5.1 Zircon U–Pb dating

5.1.1 Gabbro and plagiogranite samples

Zircons from gabbro sample 130808-08 exhibit a wide range of ages (Table 1; Figs. 7 and 8). The four youngest analyses cluster within the age range from 237 ± 4 Ma to 260 ± 4 Ma. As the analysis with the age of 237 ± 4 Ma is discordant, possibly indicating later Pb loss or disturbance by a late tectonic-magmatic event. Thus, it is excluded from the calculations. The other three young analyses with ages ranging from 258 to 260 Ma yield a weighted mean age of 259 ± 6 Ma (Fig. 8b). These three zircons are subhedral to euhedral grains with oscillatory zoning, characteristic of magmatic

crystallization (Fig. 7a and 7b). We thus consider the age of 259 ± 6 Ma to represent the time of igneous zircon crystallization. The ages of older zircons scatter from 282 ± 4 Ma to 1738 ± 23 Ma. These zircons are well-rounded grains or fragments of larger grains (Fig. 7c and 7d) and are interpreted as inherited grains.

Zircons from gabbro sample SGZ-3 exhibit a similar age spectra to that of gabbro sample 130808-08 (Table 2; Fig. 8c). Five young zircons show oscillatory zoning or widely spaced growth zones, characteristic of mafic magmatic crystallization (Fig. 7e and 7f). They give a weighted mean age of 257 ± 3 Ma (Fig. 8d), which is interpreted to be the emplacement age of the gabbro. The remaining analyzed zircons with ages ranging from ~ 278 Ma to ~ 1832 Ma are interpreted as inherited grains (Fig. 7g and 7h).

Most zircons from plagiogranite sample 141005-05 display typical oscillatory zoning (Fig. 7i and 7j), indicating a magmatic origin. The youngest seven analyses show a relatively restricted range from ~ 261 to ~ 265 Ma and yield a mean $^{206}\text{Pb}/^{238}\text{U}$ age of 263 ± 1 Ma (Fig. 8f), which is similar to the age of the gabbros within error and represents the age of igneous zircon crystallization. The older zircons with ages of 278-347 Ma (Fig. 8e) are interpreted as inherited grains (Fig. 7k and 7l).

5.1.2 Sandstone samples (140419-04 and 141005-07)

The U-Pb ages of sandstone samples 140419-04 and 141005-07 are given in Table 4. As shown in Fig. 9, the two samples show the same detrital zircon U-Pb age distribution. The main group in sandstone sample 140419-04 yielded an age peak at ~ 440 Ma (47 analyses) and a younger age peak at ~ 280 Ma (22 analyses) (Fig. 9a).

The remaining three old zircons yielded ages of ~910 Ma, ~1217 Ma, and ~1801 Ma.

The zircons with $^{206}\text{Pb}/^{238}\text{U}$ ages younger than 1000 Ma in sandstone sample 141005-07 exhibit two evident peak ages at ~440 Ma (20 analyses) and ~280 Ma (31 analyses) with a few ages of 831~954 Ma (3 analyses). Zircons older than 1000 Ma record $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 1077 Ma (1 analyses), 1503 Ma (1 analysis), ~1887 Ma (1 analysis), ~2168 Ma (1 analysis), and 2482-2540 Ma (5 analyses).

5.2 Geochemistry

5.2.1 The gabbros and basalts

The analyzed basalt and gabbro samples have SiO_2 contents of 49.7-53.8 wt. % and 44.4-47.9 wt. %, respectively. All analyzed samples are mafic in composition in regard to silica, as shown by the TAS diagram (Fig. 10a). In the $\text{FeO}^{\text{T}}/\text{MgO}$ vs SiO_2 diagram (Fig. 10b), these mafic samples plot in the tholeiitic field with only one basalt sample plotting on the tholeiitic/calc-alkaline boundary. They have low TiO_2 (0.13-0.63 wt. %) and P_2O_5 (<0.01-0.06 wt. %) contents but relatively high Al_2O_3 (14.03-19.34 wt. %) and CaO (8.36–14.14 wt. %) contents. The Mg # of the basalts and the gabbros ranges from 57 to 69 and from 67 to 77, respectively.

The basalts have low ΣREE , but they are higher than those of the gabbro samples. There is indeed a slight enrichment of LREE over HREE ($\text{La}_\text{N}/\text{Yb}_\text{N} = 0.84\text{-}2.28$), but overall, the basalts display nearly flat REE patterns similar to that of N-MORB (Fig. 11a). The basalts have high Y/Nb (6.0-17.6), Zr/Nb (11.7-53.6), and La/Nb (>1), as is typically observed for N-MORB (Montanini et al., 2008). The N-MORB affinity of the basalts is also evident in the $\text{Nb}^*2\text{-Zr}/4\text{-Y}$ diagram (Fig.13b) and the $\text{TiO}_2\text{-Nb/Yb}$

diagram (Fig. 13c). In addition, the basalts exhibit low Nb and Ta and high Sr, Pb, and Ba, while they lack negative Zr, Hf, and Ti anomalies (Fig. 12a), which are features of basalts contaminated with continental materials instead of typical subduction zone basalts (Xia, 2014).

The gabbros, however, generally have lower concentrations of P_2O_5 , Na_2O , and incompatible elements than the basalts. Their REE patterns are characterized by slightly LREE-depletion ($La_N/Yb_N = 0.57-2.31$) and nearly flat HREE like that of N-MORB (Fig. 11a). The slightly positive Eu anomalies ($Eu/Eu^* = 1.37-1.93$) (Fig. 11b) indicate the accumulation of plagioclase. Their average Sm/Nd value (0.38) is close to that of N-MORB (0.36; Sun and McDonough, 1989). In the primitive mantle (PM)-normalized spider diagram, however, the gabbros are characterized by enrichment of large ion lithophile elements (LILE) relative to high field strength elements (HFSE), which is different from typical N-MORB patterns (Fig. 12b). The Pb enrichment and Nb depletion relative to La and Th suggest involvement of continental crust or arc materials in the magma genesis (Miao et al., 2008), which may account for why the geochemical features of gabbros are not typical N-MORB. According to Pearce (2014), the involvement of trapped, relict continental lithosphere in an N-MORB magma can lead to distinctive, C (contaminated)-MORB compositions.

5.2.2 The siliceous rocks

As shown in Table 6, the siliceous rock samples from the study area consist dominantly of SiO_2 and subordinately of Al_2O_3 and $Fe_2O_3^T$ (total Fe as Fe_2O_3). Contents of SiO_2 range from 70.4 to 88.4 wt. %, lower than those in classic pelagic

siliceous rocks (Murray, 1994). Concentrations of Al_2O_3 and $\text{Fe}_2\text{O}_3^{\text{T}}$ vary from 4.03 to 15.7 wt. % and 2.84 to 6.43 wt. %, respectively. Concentrations of the other constituents are generally lower than 2 wt. %, except for those of K_2O and Na_2O .

5.2.3 Hf isotopes

Lu-Hf isotopic data for 8 young zircon grains from the two gabbro samples are presented in Table 7. The $^{176}\text{Lu}/^{177}\text{Hf}$ and $^{176}\text{Yb}/^{177}\text{Hf}$ ratios range from 0.000574 to 0.005385 and from 0.013953 to 0.134999, respectively. These 8 magmatic zircons with ages of 254-261 Ma have $\epsilon\text{Hf}(t)$ values ranging from - 5.27 to + 10.19, with the majority > 0 (Fig. 13d), suggesting that the gabbro was dominantly mantle-derived and experienced crustal contamination during magmatic evolution (Griffin et al., 2002).

6. Discussion

6.1 Formation age of the Solonker ophiolite

Our new age data for two gabbros give consistent ages and yields weighted mean ages of 259 ± 6 Ma and 257 ± 3 Ma. Zircon U-Pb dating shows that the crystallization age of the plagiogranite sample is 263 ± 1 Ma, similar to the ages of gabbros within analytical errors. In addition, a 248 ± 2 Ma gabbro has also been reported at the western segment of the Solonker ophiolite in Mongolia (Jian et al., 2008). Therefore, the Solonker ophiolite is interpreted to have formed from the late Middle-Permian to the late Late-Permian.

6.2 Sedimentary setting of Late Carboniferous-Early Permian strata

Sandstones from the Late Carboniferous-Early Permian strata on both sides of the Solonker ophiolite belt show similar age spectra (Fig. 9), indicating that they were

deposited in the same basin. The repetitive layers of reddish sandstone, siltstone, and limestone suggest that this sedimentary sequence represents shallow marine or marine-terrigenous deposits.

The peak age of ~440 Ma matches the episode of arc magmatism recognized in the NOB and the SOB (Jian et al., 2008; Xu et al., 2013), while the peak age of ~280 Ma overlaps with the age of volcanic rocks of the Dashizhai Formation (Zhang et al., 2008). Furthermore, the 431-477 Ma (Jian et al., 2008) and ~438 Ma (Miao et al., 2007) arc magmatic recognized in the study area (Fig. 2) are interpreted to be the western extension of the NOB and the SOB, respectively (Xu et al., 2015). This indicates that the Late Carboniferous-Early Permian strata was developed above the Early Paleozoic orogens, consistent with a previous interpretation (Zhao et al., 2015). The zircon U-Pb ages of ~1800 Ma and ~2500 Ma correspond to the most important tectono-thermal events of the NCC (Zhao et al., 2001, 2005; Zhai et al., 2005; Peng et al., 2010; Piper et al., 2011). In addition, sandstones from the southern side have more zircon ages of ~1800 Ma and ~2500 Ma than sandstones from the northern side. Therefore, we propose that the Late Carboniferous-Early Permian strata was deposited in an inland sea developed above the Early Paleozoic orogens on the northern margin of the NCC.

6.3 Type and tectonic setting of the Solonker ophiolite

According to Dilek (2003) and Dilek and Furnes (2011, 2014), the CM-type ophiolites generally represent ocean-continent transitional crust formed during the early stages of an ocean basin, following initial breakup of a continent. These ophiolites are characterized by widespread serpentized peridotites that are intruded

by small to moderate volumes of gabbro. They do not include sheeted dike complexes, and the peridotites underlie both basaltic lava flows and oceanic sediments (Piccardo et al., 2001). The crustal rocks display normal (N)-MORB-like geochemical signatures. Locally, the involvement of trapped, relict, continental lithosphere can lead to distinctive, contaminated, (C)-MORB compositions (Pearce, 2014).

6.3.1 Evidence for a CM-type body from petrological analyses

The SZ has long been considered as the end-Permian suture between the SC and NCC. The ophiolite fragments, together with the Carboniferous–Permian strata, were previously designated as the classic Solonker ophiolitic *mélange* developed in this area (BGMR, 1982; Xiao et al., 2003; Tao et al., 2004; Jian et al., 2010). However, our field observations reveal that the Carboniferous–Permian strata show features of normal sedimentary sequences instead of *mélange* (Figs. 3b–3e). The ultramafic blocks and siliceous blocks, occurring as olistoliths in the matrix of sandstones and siltstones, should be olistostromes developed at the bottom of a turbidite (Fig. 3f); while the large limestone blocks occurring as olistoliths in the Late Carboniferous–Early Permian strata are derived from the Amushan Formation and their tectonic emplacement is associated with the top-to-north thrusting (Fig. 3a). Furthermore, the mafic rocks experienced only low-grade metamorphism, as described in Section 3. Therefore, we suggest that the Solonker ophiolite belt and the Carboniferous–Permian strata are not the ophiolitic *mélange*. Instead, we propose that the Solonker ophiolite in the SZ may represent some dismembered ophiolite fragments, which occur as tectonic slices within the Carboniferous–Permian strata. As discussed above, on the southern side, the Late

Carboniferous-Early Permian strata are in contact with the Solonker ophiolite along high-angle south-dipping faults (Fig. 4h). Therefore, the tectonic emplacement of the Solonker ophiolite into its present location occurred due to south-dipping thrusting.

Petrologically, the Solonker ophiolite shows the following features: (a) serpentinitized peridotites make up the bulk of ophiolites, while mafic rocks are only subordinate; (b) tectonic breccias, classified as ophicalcites (Boillot and Froitzheim, 2001), overlie the serpentinitized peridotites; (c) the plutonic sequences are composed of gabbro and rare diabase without sheeted dike complexes; (d) siliceous rocks underlie the basalts (Fig. 5a); (e) significant volumes of layered mafic-ultramafic cumulates are not ubiquitous; (f) the gabbro intrudes the peridotite and basalt; and (g) the siliceous rocks directly overlie the peridotites. These are diagnostic characteristics of ophiolites formed during the early stages of the opening of an ocean basin (Boillot and Froitzheim, 2001; Desmurs et al., 2002; Dilek and Furnes, 2011, 2014). This type of ophiolite is classified as a CM-type (Dilek and Furnes, 2011, 2014) or Ligurian-type ophiolite (Dilek, 2003). Similar petrological characteristics were reported for the Ligurian and Western Alpine ophiolites (Bernoulli and Weissert, 1985; Piccardo et al., 2001; Desmurs et al., 2002; Rampone et al., 2005; Manatschal and Müntener, 2009; Dilek and Furnes, 2011) and the Jormua ophiolite in Northeastern Finland (Peltonen et al., 1996), which were interpreted to be formed in an embryonic ocean basin. In addition, the presence of sandstones and siltstones in the siliceous rock section (II) indicates that these oceanic siliceous rocks are associated with a terrigenous sedimentary system. Therefore, they may have been formed in a proximal continental

margin setting rather than in a deep-sea setting. These petrological analyses, thus, support the idea that the Solonker ophiolite is a CM-type body formed during the early stages of the opening of an ocean basin.

6.3.2 Evidence for a CM-type body from geochemistry of the mafic rocks

As described above, the mafic rocks display tholeiitic and MORB affinities, characteristic of CM-type ophiolites (Dilek and Furnes, 2011, 2014). Similar geochemical features have also been reported for other CM-type ophiolites, such as the Ligurian and Western Alpine ophiolites (Piccardo et al., 2001; Montanini et al., 2008).

Basalts carry the best records of the tectonic setting of ophiolites (Zhang, 2014). In the Ti-Zr-Y diagram (Fig. 13a), most of the basalt samples plotted within the MORB field rather than the island arc field, implying a non-subduction environment for these basalts. Whereas the one sample that plots in the island arc field may be associated with contamination by continental crust or lithosphere, which can impart subduction-like signatures (Pearce, 2008; Zhang and Zhou, 2013; Xia, 2014). This is further evidenced by the Pb enrichment and Nb depletion relative to La and Th in these mafic rocks (Fig. 12b). Moreover, no Late Paleozoic high-pressure subduction complex has been found in the study area. Therefore, the Solonker ophiolite could have formed in a MOR-like rifting environment rather than a forearc setting (e.g., Jian et al., 2010), as is also suggested in Section 5.2.1. This result further supports the conclusion based on the petrological analyses that the Solonker ophiolite is a CM-type body formed during the early stages of the opening of an ocean basin.

6.3.3 Evidence for a CM-type body from geochemistry of the siliceous rocks

Siliceous rocks provide important information on the tectonic setting of ophiolites (Girty et al., 1996; Dilek, 2003). Murray (1994) proposed the use of volatile-free values of Al_2O_3 , TiO_2 , and Fe_2O_3 to discriminate average near-ridge, pelagic (i.e., mid-oceanic), and continental margin sediments. On the $\text{Fe}_2\text{O}_3/\text{TiO}_2$ vs. $\text{Al}_2\text{O}_3/(\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3)$ and $\text{Fe}_2\text{O}_3/(100-\text{SiO}_2)$ vs. $\text{Al}_2\text{O}_3/(100-\text{SiO}_2)$ discrimination diagrams (Fig. 14), most siliceous rock samples plot within either (1) the continental margin field overlapping with the pelagic field, or (2) the continental margin field. These results suggest a continental margin depositional environment, consistent with our field observations that sandstones and siltstones are found interstratified with siliceous rocks. Similar results have been documented for siliceous rocks in the Ligurian and Western Alpine ophiolites (Manetti et al., 1979). Therefore, the geochemical analyses of the siliceous rocks again support the idea that the Solonker ophiolite is a CM-type body.

6.3.4 Evidence for a CM-type body from zircon inheritance and Hf isotopic data of the gabbros

As discussed in Section 5.1, the zircon U-Pb data indicate the presence of inherited zircons in the gabbro and plagiogranite, with ages ranging from ~280 Ma to ~1832 Ma. Zircon inheritance is common in continental igneous rocks (Pideon and Compston, 1992), but has not been previously reported in ophiolites, which are formed in oceanic environments (Miao et al., 2008). Zircon inheritance may be a common feature of ophiolites formed in immature ocean basins (Miao et al., 2008; Li et al., 2015). Representative examples of this phenomenon are the cumulate gabbros from the

Hegenshan ophiolite (Miao et al., 2008) and the plagiogranites from the Ligurian ophiolite (Borsi et al., 1996), which represent fragments of embryonic oceanic crust and contain zircons from the continental crust. Accordingly, the inherited zircons in the gabbro and plagiogranite indicate that the Solonker ophiolite may have been formed in an embryonic ocean basin. In addition, the inherited zircon ages can provide chronological information on the continental crust that was rifted to form the ocean basin. The youngest inherited zircon ages (~280 Ma) of the Solonker ophiolite correspond to the youngest peak ages (~280 Ma) of sandstones from the Late Carboniferous-Early Permian strata. Therefore, we propose that the ocean basin opened after the deposition of the Late Carboniferous-Early Permian strata.

Hf isotopic features of the gabbros suggest that crustal contamination occurred during the magmatic ascent, which further supports that the ocean basin opened between pieces of rifted continental basement.

To sum up, our new petrological, geochemical, geochronological, and Hf isotopic data indicate that the Solonker ophiolite is a CM-type body that formed in an extensional environment during the early stages of the opening of an ocean basin, following rifting and break-up of the Early Paleozoic orogens.

6.4 The Hugierte-Chaghanhadamiao volcanic-plutonic belt

Tao et al. (2003) proposed that the volcanic-plutonic belt exposed in the Hugierte-Chaghanhadamiao area is of island arc magmatism, resulting from the subduction of the PAO beneath the NCC during the Early Permian. Jian et al. (2010) suggested a forearc setting for the formation of this volcanic-plutonic belt and

interpreted it as the fragments of the Solonker ophiolite formed during the Early Permian. Chen et al. (2012) considered this unit to be part of an ophiolite complex formed in an immature ocean basin during the Early Permian. These ideas are challenged by our new field observations, and the following discussion offers alternative interpretations.

As described in Section 2.2, the volcanic rocks of this unit are mainly composed of pillow and massive basalts, dacite, and rhyolite with minor andesite (Fig. 3c), which define a bimodal succession that is consistent with the geochemical data from Jian et al. (2010). Therefore, the volcanic rocks are the products of coeval mafic and felsic volcanism commonly formed in extensional environments (Frost et al., 1999; Zhang et al., 2008), which is consistent with the field observation that this unit is sandwiched by Late Carboniferous-Early Permian strata. Additionally, the presence of rhyolite suggests that this unit is unlikely to be part of an ophiolite (Zhang et al., 2014).

The bimodal volcanic rocks that are assigned to the Dashizhai Formation to the north have magmatic eruption ages of ca. 280 Ma (IMBGMR, 1991; Zhang et al., 2008), consistent with the formation age of the Hugierte-Chaganhadamiao volcanic-plutonic sequence. It is widely accepted that the Dashizhai Formation was formed in an extensional setting (Zhu et al., 2001; Zhang et al., 2008; Zeng et al., 2011). Therefore, we suggest that this volcanic-plutonic belt is likely a part of the Dashizhai Formation rather than a component of the Solonker ophiolite.

7. Tectonic model

Based on SHRIMP zircon U-Pb ages of the Late Paleozoic ultramafic-mafic rocks

and granitoid intrusions as well as their geochemical signatures, the PAO has been considered to be closed by the latest Permian (Xiao et al., 2003; Zhang et al., 2007, 2009; Jian et al., 2008, 2010; Xiao et al., 2009). The new data in this paper suggests that these ultramafic-mafic rocks are a CM-type body formed in a newly opened ocean basin rather than the remnants of the PAO. The Late Carboniferous to Early Permian and Late Permian–Middle Triassic suite of granitoid intrusions on the northern margin of the NCC (Zhang et al., 2007, 2009) may be alkaline A-type granitoids formed in an extensional setting, such as that suggested by Shi et al. (2004) for the Early Permian granites exposed in the Xilinhot area. Therefore, we propose an intra-continental extension model to explain the evolution of the SZ during the Permian:

(1) During the Late Carboniferous–Early Permian, the Late Carboniferous–Early Permian strata were deposited in an inland sea developed on the Early Paleozoic orogens (Fig. 15A);

(2) In the Early Permian, extension of the Early Paleozoic orogens covered by the Late Carboniferous–Early Permian strata took place leading to the development of the bimodal magmatism of the Dashizhai Formation (Fig. 15B);

(3) In the Middle Permian, the Zhesi Formation developed in a weak continental extensional setting, which is supported by the observation that few coeval magmatic rocks are observed from the area (Fig. 15C);

(4) In the Late Permian, continued continental extension leads to the onset of sea-floor spreading and the development of turbidites. The Solonker ophiolite was formed during the early stages of this spreading, following rifting and break-up of the

Early Paleozoic orogens (Fig. 15D); and

(5) After the Permian, the closure of this small ocean basin led to the tectonic emplacement of the Solonker ophiolite into its present location, which occurred due to North-directed thrusting (Fig. 15E).

8. Conclusions

(1) The dating of gabbros and plagiogranites suggests that the Solonker ophiolite formed from the late Middle-Permian to the late Late-Permian.

(2) The Solonker ophiolite is not the remnant of the Paleo-Asian Ocean. Instead, it is a continental margin-type body that formed during the early stages of opening of an ocean basin, following rifting and break-up of the Early Paleozoic orogens covered by Late Carboniferous-Early Permian strata.

(3) The tectonic evolution of the Solonker zone in the Permian is characterized by intra-continental extension.

Acknowledgements

We thank Wang Yanyang, Liao Wen, Zhang Chenhao and Yan Linjie for their help in field trips, Su Li and Ma Fang for their help in ICP-MS analyses of zircons. We gratefully acknowledge constructive reviews from three anonymous reviewers. This work has been funded by the National Key Basic Research Program of China (2013CB429806), and the National Science Foundation of China (40872145 and 41121062).

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Figure Captions

Fig. 1. (a) The location of the XMOB in central and East Asia (after Şengör et al., 1993). (b) Geological sketch map of the XMOB showing the distribution of late Paleozoic strata and the main tectonic units (Jian et al., 2008; Heumann et al., 2012; Chen et al., 2015; Xu et al., 2015).

Fig. 2. Simplified geological map of the study area (after Wang et al., 2005; Jian et al., 2010). The dashed line marks the China/Mongolia border. Lines I and II show the locations of the sections displayed in Figure 6.

Fig. 3. Simplified stratigraphic section and field photos of Late Carboniferous-Permian strata in the study area. a. Limestones of the Late Carboniferous Amushan Formation occur as nappes above the Late Carboniferous-Early Permian strata. b. Red coarse-grained sandstones of the Late Carboniferous-Early Permian strata. c. Bimodal distribution of volcanic rocks among the Early Permian volcanic-plutonic sequence. d. Repetitive layers of pebbly sandstones and limestones in the Middle Permian Zhesi Formation. e. Bouma sequences in the Late Permian turbidite. f. Olistostromes showing ultramafic blocks in the matrix of sandstones and siltstones at the bottom of the turbidite.

Fig. 4. Field photos of the different members of the Solonker ophiolite. See text for details.

Fig. 5. Photomicrographs of the different members of the Solonker ophiolite.

Fig. 6. Geological section of the Solonker ophiolite showing the sample locations. a. Geological section of the mafic rocks occurring in the Wuzhuershaobute area. b.

Geological section of the siliceous rocks exposed near Bayanaobao.

Fig. 7. Representative CL images of zircons from gabbro sample 130808-08 (a-d), gabbro sample SGZ-3 (e-h), and plagiogranite sample 141005-05 (i-l).

Fig. 8. Concordia plot of U–Pb zircon analytical results for gabbros and plagiogranites from the Solonker ophiolite.

Fig. 9. Relative age probability diagram for sample 140419-04 and sample 141005-07, which were collected from the north side and the south side of the Solonker ophiolite belt, respectively.

Fig. 10. (a) Silica vs. total Alkalis (TAS) diagram (Le Maitre et al., 1989) of basalt and gabbro samples. (b) Plot of SiO_2 versus FeOT/MgO (after Miyashiro, 1974) for basalt and gabbro samples. Symbols in Fig. 11 and Fig. 13 are the same as those in this figure.

Fig. 11. Chondrite normalized REE patterns for the (a) gabbros and (b) basalts of the Solonker ophiolite (E-MORB, OIB compositions and N-MORB normalization values are from Sun and McDonough, 1989).

Fig. 12. Primitive mantle-normalized spider diagrams for the (a) gabbros and (b) basalts of the Solonker ophiolite (normalization values are from Sun and McDonough, 1989).

Fig. 13. Plots of (a) $\text{Ti}/100\text{-Zr-Y}^*3$ (after Pearce and Cann, 1973), (b) $\text{Nb}^*2\text{-Zr}/4\text{-Y}$ (after Meschede, 1986), (c) $\text{TiO}_2\text{-Nb/Yb}$ (after Pearce 2014), and (d) ϵHf_t versus crystallization ages of zircons from the gabbros in the study area (Gerdes and Zeh, 2006). MORB = Mid Ocean Ridge Basalts; OIB = oceanic island basalt; N-MORB =

Normal Mid-Ocean Ridge Basalts; P-MORB = Plume-influenced Mid-Ocean Ridge Basalts; and E-MORB = Enriched Mid-Ocean Ridge Basalts.

Fig. 14. a. $\text{Fe}_2\text{O}_3/(100\text{-SiO}_2)$ vs $\text{Al}_2\text{O}_3/(100\text{-SiO}_2)$ discrimination diagram from Murray (1994). b. $\text{Fe}_2\text{O}_3/\text{TiO}_2$ vs $\text{Al}_2\text{O}_3/(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$ from Murry (1994).

Fig. 15. Generalized evolutionary model for the Solonker zone during the Permian (modified after Lagabriele and Lemoine, 1997; Piccardo et al., 2001; Dilek and Furnes, 2011). SZ: Solonker zone; NCC: North China craton; SOB: Southern orogenic belt; and NOB: Northern orogenic belt.

Figure

Figure

Figure

Late Permian	<div> Solonker ophiolite </div> <div> Turbidite </div>
Middle Permian	Zhesi Formation: Clastic-carbonate rocks
Early Permian	<div> Dashizhai Formation: Bimodal succession </div> <div> Volcanic-plutonic sequence </div>
Late Carboniferous to Early Permian	Carbonate-clastic rocks
Late Carboniferous	Amushan Formation: Limestone

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Table 1. SIMS zircon U-Pb data of gabbro sample 130808-08 from the Solonker ophiolite.

Spot	Concentritions (ppm)			Isotopic ratios				
	U	Th	Pb	Th/U	$^{207}\text{Pb}/^{235}\text{U}$	1 σ %	$^{206}\text{Pb}/^{238}\text{U}$	1 σ %
130808-08@4	2016	1630	97	0.809	0.26179	2.23	0.0374	1.51
130808-08@1	3328	2098	162	0.630	0.28056	4.82	0.0409	1.51
130808-08@10	585	1349	42	2.307	0.27455	5.04	0.0410	1.52
130808-08@11	825	1515	56	1.836	0.28211	3.81	0.0412	1.52
130808-08@2	906	245	46	0.271	0.31707	2.71	0.0447	1.54
130808-08@17	703	350	39	0.498	0.32525	3.02	0.0463	1.51
130808-08@5	928	408	51	0.440	0.32110	4.15	0.0469	1.51
130808-08@19	673	463	41	0.688	0.32966	5.13	0.0488	1.50
130808-08@13	1305	1108	91	0.849	0.43458	4.02	0.0551	1.51
130808-08@7	1909	2711	138	1.420	0.31918	4.75	0.0573	1.50
130808-08@6	955	195	69	0.205	0.48410	2.04	0.0647	1.50
130808-08@9	499	336	42	0.675	0.47627	6.01	0.0667	1.56
130808-08@18	1115	1376	109	1.234	0.53330	13.12	0.0686	1.65
130808-08@15	626	355	54	0.568	0.48714	5.33	0.0701	1.51
130808-08@14	1531	722	137	0.472	0.47589	3.61	0.0776	1.50
130808-08@16	1275	182	214	0.143	1.39644	2.37	0.1526	1.50
130808-08@12	258	398	83	1.543	2.72486	6.57	0.2298	1.54
130808-08@3	2680	1295	795	0.483	2.95023	1.55	0.2403	1.50
130808-08@20	1393	30	484	0.022	4.97661	1.57	0.3095	1.51

Table 1. (Continued)

Age(Ma)						Concordanty
$^{207}\text{Pb}/^{206}\text{Pb}$	1 $\sigma\%$	$^{207}\text{Pb}/^{235}\text{U}$	1 $\sigma\%$	$^{206}\text{Pb}/^{238}\text{U}$	1 $\sigma\%$	%
231.4	37.5	236.1	4.7	236.6	3.5	-0.21
184.2	103.3	251.1	10.8	258.3	3.8	-2.79
127.7	109.3	246.3	11.1	258.9	3.9	-4.87
178	79.6	252.3	8.6	260.4	3.9	-3.11
262.2	50.3	279.6	6.6	281.7	4.2	-0.75
237.8	59.2	285.9	7.5	291.9	4.3	-2.06
178.3	87.7	282.8	10.3	295.5	4.4	-4.30
146.8	111.1	289.3	13	307.2	4.5	-5.83
499.5	80.1	366.4	12.4	345.7	5.1	5.99
-327	112.1	281.3	11.7	359.4	5.2	-21.73
382.4	30.7	400.9	6.8	404.1	5.9	-0.79
277.2	127.8	395.5	19.9	416	6.3	-4.93

468.6	264.9	434	47.4	427.5	6.8	1.52
214.5	114.4	403	17.9	436.6	6.4	-7.70
-85.3	78.7	395.2	11.9	482	7	-18.01
818.5	37.8	887.4	14.1	915.3	12.8	-3.05
1338.1	118.7	1335.3	50	1333.5	18.6	0.34
1405	7.7	1394.9	11.9	1388.3	18.8	1.20
1905.1	7.7	1815.4	13.3	1738.2	23	9.60

Table

Table 2. LA-ICP-MS zircon U-Pb data of gabbro sample SGZ-3 from the Solonker ophiolite

Spot	Concentritions (ppm)			Isotopic ratios				Age(Ma)				Concordanty			
	U	Th	Pb	Th/U	²⁰⁷ Pb/ ²³⁵		²⁰⁶ Pb/ ²³⁸		²⁰⁷ Pb/ ²⁰⁶ P		²⁰⁷ Pb/ ²³⁵		²⁰⁶ Pb/ ²³⁸		%
					U	1σ	U	1σ	b	1σ	U	1σ	U	1σ	
SGZ-01	211	113	12	0.54	0.3908	0.0134	0.0534	0.0007	333	54	335	10	335	4	0.00
SGZ-02	638	346	29	0.54	0.2941	0.01	0.0413	0.0005	269	54	262	8	261	3	0.38
SGZ-03	222	105	18	0.47	0.6292	0.0233	0.0744	0.001	652	57	496	15	462	6	7.36
SGZ-04	473	262	23	0.55	0.3161	0.0329	0.044	0.001	288	193	279	25	278	6	0.36
SGZ-05	84	70	5	0.83	0.3276	0.0323	0.0458	0.0007	279	195	288	25	289	4	-0.35
SGZ-06	406	266	79	0.65	1.7598	0.0347	0.1691	0.0021	1081	20	1031	13	1007	12	7.35
SGZ-07	626	687	50	1.1	0.4836	0.0123	0.0641	0.0008	400	34	401	8	400	5	0.25
SGZ-08	199	95	13	0.48	0.4415	0.018	0.0592	0.0008	374	68	371	13	371	5	0.00
SGZ-09	330	130	14	0.4	0.2846	0.0097	0.0403	0.0005	253	54	254	8	254	3	0.00
SGZ-10	262	130	17	0.5	0.4427	0.0158	0.0595	0.0008	367	56	372	11	373	5	-0.27
SGZ-11	254	308	109	1.21	5.4291	0.0971	0.3287	0.0042	1953	16	1889	15	1832	20	6.60
SGZ-12	121	75	8	0.62	0.4233	0.0263	0.0573	0.0008	354	116	358	19	359	5	-0.28
SGZ-13	475	193	3	0.41	0.0493	0.0065	0.0069	0.0001	296	264	49	6	44	0.7	11.36
SGZ-14	209	85	12	0.41	0.384	0.0175	0.0526	0.0007	328	79	330	13	330	4	0.00
SGZ-15	727	547	34	0.75	0.2876	0.0071	0.0406	0.0005	257	33	257	6	257	3	0.00
SGZ-16	646	428	28	0.66	0.3337	0.0083	0.0379	0.0005	734	31	292	6	240	3	21.67
SGZ-17	335	181	19	0.54	0.378	0.0124	0.0518	0.0007	323	51	326	9	326	4	0.00
SGZ-18	142	130	8	0.92	0.356	0.0188	0.0492	0.0007	308	95	309	14	309	4	0.00

SGZ-19 177 187	₆₄	1.05	3.9654	0.0745	0.2847	0.0036	1642	18	1627	15	1615	18	1.67
SGZ-20 565 291	₃₇	0.52	0.4524	0.0105	0.0598	0.0008	406	30	379	7	374	5	1.34
SGZ-21 580 409	₂₆	0.71	0.2937	0.0137	0.038	0.0005	455	111	261	11	240	3	8.75
SGZ-22 482 529	₂₄	1.1	0.2863	0.0096	0.0405	0.0005	254	54	256	8	256	3	0.00
SGZ-23 209 187	₁₀	0.9	0.3124	0.0106	0.0419	0.0006	371	52	276	8	265	3	4.15
SGZ-24 431 205	₁₉	0.48	0.2852	0.0076	0.0403	0.0005	255	37	255	6	255	3	0.00

Table 3. LA-ICP-MS zircon U-Pb data of plagiogranite sample 141005-05 from the Solonker ophiolite.

Spot name	Corrected ratios							
	$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{206}\text{Pb}/^{238}\text{U}$	1 σ	$^{208}\text{Pb}/^{232}\text{Th}$	1 σ
0505-01	0.05279	0.00693	0.35864	0.04672	0.04928	0.00095	0.01755	0.00055
0505-02	0.05339	0.00211	0.4064	0.01585	0.05523	0.00067	0.01844	0.00028
0505-03	0.05206	0.00329	0.32351	0.0201	0.04508	0.00072	0.01477	0.00041
0505-04	0.05151	0.00297	0.29786	0.017	0.04195	0.00056	0.01336	0.00023
0505-05	0.05216	0.00323	0.3328	0.02033	0.04629	0.00069	0.01587	0.00033
0505-06	0.08688	0.00592	0.52457	0.03458	0.04379	0.00075	0.01298	0.00019
0505-07	0.05183	0.00777	0.31496	0.04709	0.04409	0.00067	0.01631	0.00047
0505-08	0.05147	0.00446	0.29297	0.02482	0.04129	0.00092	0.01395	0.00062
0505-09	0.05147	0.00313	0.29502	0.01784	0.04158	0.00051	0.01295	0.00028
0505-10	0.05155	0.00268	0.29723	0.01506	0.04183	0.00066	0.01375	0.00029
0505-11	0.36186	0.00738	3.59384	0.05711	0.07203	0.00092	0.0186	0.00179
0505-12	0.05144	0.0061	0.29614	0.0349	0.04177	0.0007	0.01252	0.00057
0505-13	0.09308	0.00595	0.57402	0.03451	0.04473	0.00097	0.01316	0.0003
0505-14	0.05146	0.00202	0.29469	0.01127	0.04155	0.00056	0.0131	0.00023
0505-15	0.08072	0.00369	0.48045	0.0209	0.04317	0.0006	0.01289	0.00016
0505-16	0.08477	0.00559	0.54997	0.03489	0.04705	0.00086	0.01398	0.00023
0505-17	0.08591	0.00409	0.54611	0.0249	0.04611	0.00063	0.01368	0.00019
0505-18	0.05144	0.0033	0.29361	0.01843	0.04141	0.0007	0.01358	0.00034
0505-19	0.05187	0.00305	0.31554	0.01819	0.04413	0.00068	0.01413	0.00034
0505-20	0.07793	0.00493	0.45865	0.02798	0.04269	0.00072	0.0128	0.00018
0505-21	0.05196	0.00324	0.31713	0.01942	0.04428	0.00068	0.01385	0.00047
0505-22	0.05872	0.0023	0.34602	0.01285	0.04274	0.00054	0.01323	0.00014
0505-23	0.05197	0.00304	0.32077	0.0183	0.04477	0.00075	0.01309	0.00039
0505-24	0.0523	0.00261	0.34082	0.01668	0.04727	0.00069	0.0157	0.00036
0505-25	0.052	0.00585	0.32462	0.03618	0.04529	0.00086	0.01568	0.0005

Table 3. (Continued)

Corrected ages (Ma)								Concordanty
$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{206}\text{Pb}/^{238}\text{U}$	1 σ	$^{208}\text{Pb}/^{232}\text{Th}$	1 σ	(%)
320	259	311	35	310	6	352	11	0.32
345	66	346	11	347	4	369	6	-0.29
288	113	285	15	284	4	296	8	0.35
264	107	265	13	265	3	268	5	0.00
292	113	292	15	292	4	318	7	0.00
1358	135	428	23	276	5	261	4	55.07
278	297	278	36	278	4	327	9	0.00

262	151	261	19	261	6	280	12	0.00
262	117	263	14	263	3	260	6	0.00
266	87	264	12	264	4	276	6	0.00
3758	32	1548	13	448	6	372	36	245.54
261	236	263	27	264	4	251	11	-0.38
1490	124	461	22	282	6	264	6	63.48
261	63	262	9	262	3	263	5	0.00
1215	92	398	14	272	4	259	3	46.32
1310	132	445	23	296	5	281	5	50.34
1336	94	442	16	291	4	275	4	51.89
261	113	261	14	262	4	273	7	-0.38
280	104	278	14	278	4	284	7	0.00
1145	129	383	19	269	4	257	4	42.38
284	112	280	15	279	4	278	9	0.36
557	88	302	10	270	3	266	3	11.85
284	100	282	14	282	5	263	8	0.00
299	85	298	13	298	4	315	7	0.00
285	217	285	28	286	5	314	10	-0.35

Table 4. Detrital zircon U-Pb ages of sandtones from both south and north sides of the Solonker ophiolite belt.

Spot name	Corrected ratios							
	$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{206}\text{Pb}/^{238}\text{U}$	1 σ	$^{208}\text{Pb}/^{232}\text{Th}$	1 σ
Sample141005-07								
0507-01	0.05178	0.00276	0.31008	0.01635	0.04343	0.00053	0.01419	0.00020
0507-02	0.05561	0.00136	0.53542	0.01271	0.06982	0.0008	0.02166	0.00034
0507-03	0.05173	0.00178	0.30954	0.0103	0.04339	0.00057	0.01431	0.00020
0507-04	0.05261	0.00256	0.35899	0.01697	0.04948	0.00076	0.01609	0.00031
0507-05	0.05532	0.00133	0.5209	0.01211	0.06828	0.00077	0.02215	0.00030
0507-06	0.05212	0.00213	0.33287	0.01324	0.04632	0.00065	0.01487	0.00023
0507-07	0.05193	0.00402	0.31919	0.02451	0.04458	0.00061	0.01476	0.00023
0507-08	0.05465	0.00298	0.50468	0.02673	0.06697	0.00088	0.02091	0.00021
0507-09	0.07089	0.00158	1.56009	0.03375	0.15961	0.00186	0.05156	0.00087
0507-10	0.05546	0.00124	0.52662	0.01143	0.06887	0.00076	0.02336	0.0004
0507-11	0.05177	0.00153	0.3131	0.00899	0.04386	0.00053	0.01469	0.00020
0507-12	0.05213	0.01176	0.3341	0.07508	0.04648	0.00106	0.01723	0.00063
0507-13	0.05576	0.00123	0.54697	0.01171	0.07114	0.00079	0.02306	0.00033
0507-14	0.06226	0.00194	0.87126	0.02539	0.10149	0.00112	0.03121	0.00037
0507-15	0.05537	0.00109	0.52066	0.00988	0.0682	0.00073	0.02149	0.00032
0507-16	0.16312	0.00255	10.596	0.16102	0.47115	0.00522	0.13641	0.00223
0507-17	0.16254	0.00354	10.5164	0.22602	0.46928	0.00634	0.12794	0.00253
0507-18	0.05537	0.00155	0.52175	0.01417	0.06835	0.00082	0.02262	0.0004
0507-19	0.05247	0.00206	0.35101	0.01351	0.04852	0.00061	0.01567	0.00028
0507-20	0.05238	0.00156	0.34631	0.01001	0.04795	0.00057	0.01555	0.00028
0507-21	0.05275	0.00125	0.36676	0.00838	0.05043	0.00057	0.01579	0.00024
0507-22	0.06846	0.00256	0.68436	0.02497	0.07251	0.00094	0.02845	0.00050
0507-23	0.05183	0.00226	0.31469	0.01336	0.04404	0.00064	0.01398	0.00027
0507-24	0.05221	0.00171	0.33498	0.01065	0.04653	0.00058	0.01518	0.0003
0507-25	0.05192	0.00169	0.31781	0.01008	0.0444	0.00055	0.01455	0.00020
0507-26	0.05203	0.00234	0.32571	0.01429	0.04541	0.00064	0.01416	0.0003
0507-27	0.07587	0.0023	0.60559	0.01703	0.05789	0.00065	0.01741	0.00019
0507-28	0.05636	0.0014	0.58019	0.014	0.07467	0.00085	0.02362	0.00042
0507-29	0.05657	0.00167	0.5972	0.01708	0.07657	0.00095	0.02339	0.00042
0507-30	0.05195	0.00173	0.32046	0.01038	0.04475	0.00056	0.01417	0.00020
0507-31	0.05525	0.00139	0.5159	0.01261	0.06773	0.00078	0.02266	0.00042
0507-32	0.05664	0.00186	0.59798	0.01904	0.07659	0.00099	0.02851	0.00050
0507-33	0.05206	0.00139	0.32869	0.00854	0.0458	0.00053	0.01471	0.00023
0507-34	0.16548	0.0027	10.87376	0.17301	0.47666	0.00526	0.13676	0.00247

0507-35	0.05553	0.00183	0.53118	0.01716	0.06939	0.00082	0.02313	0.00040
0507-36	0.16434	0.003	10.73776	0.19211	0.47397	0.00569	0.1267	0.00210
0507-37	0.05212	0.00232	0.33227	0.01439	0.04625	0.00067	0.01543	0.00035
0507-38	0.05237	0.00374	0.34523	0.02439	0.04782	0.00072	0.01591	0.00038
0507-39	0.05294	0.00205	0.37801	0.0143	0.05179	0.00066	0.01718	0.00035
0507-40	0.05167	0.00208	0.30537	0.01209	0.04287	0.00054	0.01447	0.00028
0507-41	0.0522	0.00269	0.33668	0.01716	0.04679	0.00059	0.01488	0.0003
0507-42	0.16821	0.00309	11.20126	0.2017	0.48306	0.00577	0.1399	0.00290
0507-43	0.05203	0.00211	0.32438	0.01277	0.04523	0.00062	0.0151	0.00032
0507-44	0.16276	0.0027	10.54478	0.17012	0.46999	0.00506	0.14096	0.00235
0507-45	0.05269	0.00197	0.36562	0.01329	0.05034	0.00067	0.01573	0.0003
0507-46	0.0523	0.00155	0.34317	0.00991	0.0476	0.00057	0.01567	0.0003
0507-47	0.05219	0.00299	0.32097	0.01813	0.04462	0.00063	0.01523	0.00037
0507-48	0.05619	0.00143	0.57145	0.0141	0.07378	0.00086	0.02348	0.00051
0507-49	0.05504	0.00259	0.50149	0.0232	0.0661	0.0009	0.0212	0.0006
0507-50	0.1659	0.00291	10.9306	0.18722	0.478	0.00525	0.13568	0.0024
0507-51	0.05411	0.00314	0.32877	0.01875	0.04408	0.00067	0.01412	0.00031
0507-52	0.11546	0.00217	5.41805	0.09923	0.34044	0.0038	0.09837	0.00175
0507-53	0.05495	0.00156	0.49674	0.01371	0.06558	0.0008	0.02157	0.0004
0507-54	0.05528	0.00169	0.51569	0.01535	0.06768	0.00083	0.02185	0.00045
0507-55	0.05545	0.00142	0.526	0.01315	0.06882	0.00078	0.02222	0.00043
0507-56	0.05812	0.00208	0.39527	0.01388	0.04934	0.00061	0.01668	0.00032
0507-57	0.05216	0.0028	0.33262	0.01756	0.04626	0.00066	0.01599	0.00042
0507-58	0.05298	0.00189	0.38053	0.01328	0.05211	0.00066	0.01831	0.00038
0507-59	0.0668	0.00248	1.22634	0.04314	0.13315	0.00157	0.04062	0.00043
0507-60	0.05256	0.00582	0.35683	0.03911	0.04925	0.00098	0.01704	0.00052
0507-61	0.05196	0.00504	0.31929	0.0308	0.04458	0.00067	0.0138	0.00043
0507-62	0.05497	0.00182	0.48997	0.01588	0.06467	0.00079	0.02036	0.00041
0507-63	0.05974	0.00288	0.64358	0.0305	0.07816	0.00111	0.02236	0.00087
0507-64	0.07531	0.00176	1.88411	0.0429	0.1815	0.00214	0.05572	0.00118
0507-65	0.05202	0.00207	0.32425	0.01262	0.04522	0.0006	0.01525	0.00032
0507-66	0.05175	0.00254	0.31158	0.01506	0.04368	0.00058	0.01371	0.0003
0507-67	0.06951	0.0018	1.31381	0.0307	0.13707	0.00152	0.04163	0.00043
0507-68	0.05233	0.00261	0.33348	0.01633	0.04623	0.00066	0.01448	0.00032
0507-69	0.05204	0.00244	0.32609	0.01487	0.04546	0.00068	0.01446	0.00030
0507-70	0.09375	0.00225	3.31518	0.07766	0.25656	0.00308	0.07307	0.00160
0507-71	0.13534	0.00307	7.17551	0.14231	0.38453	0.00421	0.10891	0.00110
0507-72	0.053	0.00268	0.38087	0.01885	0.05214	0.00077	0.01694	0.00042
0507-73	0.05575	0.00138	0.54435	0.01314	0.07085	0.00082	0.02344	0.00052
0507-74	0.05238	0.00428	0.33064	0.02678	0.0458	0.00068	0.01484	0.00037

0507-75	0.05579	0.0017	0.54684	0.01622	0.07111	0.00088	0.02317	0.00053
Sample140419-04								
1904-01	0.05541	0.0012	0.52596	0.0108	0.06887	0.0007	0.02314	0.00031
1904-02	0.05541	0.0009	0.52682	0.00797	0.06898	0.00065	0.02164	0.00023
1904-03	0.05171	0.00142	0.30715	0.00811	0.04309	0.00046	0.01381	0.00018
1904-04	0.05627	0.00197	0.57878	0.01955	0.07462	0.00093	0.02445	0.00039
1904-05	0.06939	0.00145	1.45205	0.02867	0.15181	0.00161	0.04727	0.00062
1904-06	0.05578	0.00139	0.54722	0.01301	0.07116	0.00076	0.02251	0.00034
1904-07	0.05614	0.00155	0.56855	0.015	0.07347	0.00082	0.0223	0.00033
1904-08	0.056	0.00121	0.56254	0.01154	0.07287	0.00074	0.02284	0.00029
1904-09	0.0522	0.00146	0.33345	0.00898	0.04634	0.0005	0.01592	0.00021
1904-10	0.05196	0.00428	0.32321	0.02627	0.04512	0.00075	0.01452	0.00034
1904-11	0.05576	0.00155	0.54466	0.01453	0.07086	0.0008	0.02308	0.00033
1904-12	0.05551	0.00161	0.53233	0.01482	0.06957	0.00079	0.02246	0.00034
1904-13	0.05182	0.00142	0.31396	0.00824	0.04396	0.00047	0.01477	0.00019
1904-14	0.05387	0.0035	0.50086	0.03195	0.06746	0.00105	0.0194	0.00072
1904-15	0.05154	0.00215	0.29018	0.01173	0.04084	0.00055	0.01378	0.00020
1904-16	0.07345	0.00171	0.78339	0.01722	0.07737	0.00083	0.02798	0.00036
1904-17	0.05208	0.00227	0.32933	0.01391	0.04587	0.00063	0.01458	0.00020
1904-18	0.05542	0.00119	0.52555	0.01066	0.0688	0.0007	0.02196	0.00029
1904-19	0.05277	0.0002	0.36665	0.01348	0.05041	0.00061	0.01679	0.00029
1904-20	0.05127	0.00168	0.32168	0.01014	0.04551	0.00053	0.01522	0.00023
1904-21	0.05571	0.00322	0.54269	0.03034	0.07066	0.0013	0.02209	0.0006
1904-22	0.05554	0.00121	0.55082	0.01141	0.07195	0.00073	0.02338	0.00034
1904-23	0.05541	0.00144	0.52429	0.01301	0.06864	0.00074	0.02191	0.00031
1904-24	0.05512	0.00153	0.51153	0.01367	0.06732	0.00073	0.02152	0.0003
1904-25	0.05217	0.00177	0.33431	0.01094	0.04649	0.00056	0.01546	0.00023
1904-26	0.05222	0.00154	0.33416	0.00947	0.04642	0.00052	0.01498	0.0002
1904-27	0.05591	0.0019	0.55401	0.01829	0.07188	0.00078	0.02306	0.00039
1904-28	0.0561	0.00215	0.56618	0.02096	0.07322	0.00095	0.02307	0.00047
1904-29	0.05526	0.00137	0.53004	0.01262	0.06958	0.00072	0.02295	0.00033
1904-30	0.05189	0.00237	0.3191	0.0142	0.04461	0.00056	0.01398	0.00029
1904-31	0.05598	0.00145	0.56047	0.01394	0.07264	0.00078	0.02259	0.00036
1904-32	0.05554	0.00198	0.52997	0.0182	0.06922	0.00088	0.0229	0.00044
1904-33	0.05636	0.00203	0.57741	0.02006	0.07433	0.00097	0.024	0.00046
1904-34	0.05555	0.0015	0.53258	0.01378	0.06955	0.00075	0.02287	0.00034
1904-35	0.05546	0.00148	0.52969	0.01346	0.06928	0.00076	0.02104	0.00031
1904-36	0.05561	0.00269	0.53613	0.02546	0.06993	0.00087	0.02482	0.00043
1904-37	0.05559	0.00152	0.54856	0.01446	0.07159	0.00076	0.02264	0.00036

1904-38	0.05187	0.00172	0.31696	0.01017	0.04433	0.00049	0.01436	0.00023
1904-39	0.05184	0.00181	0.31598	0.01064	0.04422	0.00054	0.01418	0.00023
1904-40	0.0518	0.00191	0.3138	0.0112	0.04394	0.00052	0.0141	0.00021
1904-41	0.08083	0.00134	2.31501	0.03558	0.20776	0.00203	0.06333	0.00082
1904-42	0.05567	0.0014	0.54072	0.01295	0.07046	0.00074	0.02271	0.00032
1904-43	0.05635	0.00232	0.58261	0.02313	0.07501	0.00105	0.02351	0.00046
1904-44	0.05569	0.00228	0.53955	0.0216	0.07029	0.00082	0.02365	0.00049
1904-45	0.05189	0.00149	0.31545	0.0087	0.0441	0.00048	0.01396	0.00023
1904-46	0.05578	0.00158	0.54762	0.01495	0.07122	0.00075	0.02308	0.00038
1904-47	0.05597	0.00171	0.55961	0.01648	0.07253	0.00082	0.02344	0.00039
1904-48	0.0556	0.00106	0.53772	0.00964	0.07016	0.00068	0.02199	0.0003
1904-49	0.05217	0.00187	0.3362	0.01165	0.04675	0.00057	0.01559	0.00028
1904-50	0.05541	0.00136	0.52597	0.01229	0.06886	0.00073	0.02159	0.00033
1904-51	0.05183	0.00316	0.31413	0.0187	0.04396	0.00068	0.01432	0.00033
1904-52	0.05538	0.00149	0.52379	0.01347	0.06861	0.00074	0.02187	0.00033
1904-53	0.0552	0.00145	0.51148	0.01278	0.06722	0.00073	0.02153	0.00034
1904-54	0.05545	0.001	0.52933	0.00885	0.06925	0.00066	0.02286	0.00031
1904-55	0.05576	0.00149	0.54786	0.01401	0.07128	0.00075	0.02291	0.00034
1904-56	0.05175	0.0016	0.31247	0.0093	0.0438	0.00049	0.01418	0.00022
1904-57	0.05552	0.00148	0.53007	0.01347	0.06926	0.00074	0.02236	0.00033
1904-58	0.05603	0.00142	0.5634	0.01359	0.07294	0.00077	0.02307	0.00039
1904-59	0.05178	0.0016	0.31222	0.00924	0.04374	0.0005	0.0143	0.00023
1904-60	0.05567	0.00166	0.53916	0.01539	0.07026	0.0008	0.02303	0.00038
1904-61	0.05562	0.00105	0.53887	0.00947	0.07028	0.00068	0.02259	0.00032
1904-62	0.05573	0.00163	0.54435	0.01527	0.07086	0.0008	0.02233	0.0004
1904-63	0.05554	0.00118	0.53432	0.01071	0.06979	0.0007	0.02309	0.00033
1904-64	0.05193	0.00165	0.31973	0.00979	0.04466	0.0005	0.01464	0.00023
1904-65	0.05582	0.00162	0.54819	0.01528	0.07124	0.0008	0.02401	0.00042
1904-66	0.1101	0.00171	4.89548	0.06988	0.32254	0.0031	0.0988	0.0014
1904-67	0.06006	0.00303	0.45392	0.02234	0.05483	0.00075	0.01899	0.00034
1904-68	0.05168	0.00135	0.30582	0.00765	0.04293	0.00045	0.01442	0.00021
1904-69	0.05582	0.00157	0.54927	0.01471	0.07138	0.0008	0.0224	0.00043
1904-70	0.05562	0.00152	0.53849	0.01401	0.07023	0.00078	0.02288	0.00039
1904-71	0.05221	0.00241	0.33499	0.01504	0.04654	0.00064	0.0142	0.00031
1904-72	0.05546	0.00171	0.5413	0.01607	0.0708	0.00079	0.02385	0.00042
1904-73	0.05627	0.0012	0.57571	0.01152	0.07421	0.00074	0.02486	0.00037
1904-74	0.05208	0.00163	0.33029	0.00995	0.04601	0.00051	0.01447	0.00024
1904-75	0.05626	0.00191	0.57541	0.01874	0.07419	0.0009	0.02269	0.00043

Table 5. Major and trace element compositions (ppm) of mafic rocks from the Solonker ophiolite.

Sample	130928-01	130928-02	130928-04	130814-12	130808-09	130808-10	130808-12	130808-13	130808-14
Rock type	Basalt	Basalt	Basalt	Basalt	Gabbro	Gabbro	Gabbro	Gabbro	Gabbro
SiO ₂	49.68	50.75	51.51	53.82	47.9	47.22	45.54	47.74	47.74
TiO ₂	0.63	0.43	0.37	0.36	0.52	0.51	0.13	0.13	0.13
Al ₂ O ₃	19.34	15.48	14.03	15.48	15.91	16.42	18.71	13.07	13.07
Fe ₂ O ₃	8.16	8.22	10.25	6.98	9.03	8.83	7.7	8.09	8.09
FeO	3.14	4.19	7.48	3.89	6.2	5.87	5.67	6.15	6.15
MnO	0.12	0.12	0.18	0.13	0.16	0.15	0.16	0.15	0.15
MgO	5.49	8.72	9.34	7.77	9.05	9.07	10.51	13.17	13.17
CaO	9.42	10.04	8.41	8.36	13.83	14.14	12.87	13.51	13.51
Na ₂ O	4	3.67	3.29	4.3	1.15	1.18	1.22	0.77	0.77
K ₂ O	0.03	0.06	0.1	0.07	0.13	0.2	0.47	0.37	0.37
P ₂ O ₅	0.06	0.03	0.02	0.04	<0.01	<0.01	<0.01	<0.01	<0.01
LOI	2.9	2.2	2.3	2.5	2.1	2	2.4	2.5	2.5
Sum	99.83	99.79	99.77	99.83	99.79	99.78	99.77	99.72	99.72
Mg#	0.57	0.68	0.65	0.69	0.67	0.67	0.73	0.77	0.77
Sc	29	35	40	33	49	42	37	30	30
V	236	217	271	205	238	238	120	200	200
Cr	54.74	390	136.84	280.53	41.05	198.42	157.37	1046.84	1046.84
Co	24.3	35.4	45.8	32.1	40.6	38.7	45.1	46.2	46.2
Ni	33.5	78	36.9	64.6	10.3	30.2	27	70.9	70.9
Cu	108.5	28	62.9	23.9	19.6	8.9	10.9	19.1	19.1
Zn	57	26	31	11	16	24	57	42	42
Ga	16.2	11.5	10.7	9.3	12.8	13.9	10.8	10.2	10.2
Rb	0.6	0.8	2.3	1.2	2.7	5	10.4	10.1	10.1
Sr	241	153.7	131.4	118.8	144.1	184.5	170.1	123	123
Zr	46.8	28.8	10.5	26.8	4.8	11.1	3.7	6.1	6.1
Nb	2.2	1.5	0.9	0.5	<0.1	<0.1	<0.1	<0.1	<0.1
Ta	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cs	0.5	0.1	0.2	<0.1	0.4	0.3	0.4	0.2	0.2
Ba	35	47	72	53	16	54	42	11	11
Hf	1.4	0.8	0.4	0.8	0.2	0.4	0.1	0.2	0.2
Pb	0.5	0.2	0.6	0.5	0.6	1	1	0.2	0.2
Th	0.7	0.5	<0.2	0.5	<0.2	<0.2	<0.2	<0.2	<0.2
U	0.4	0.1	0.2	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
La	4.2	2.8	1.4	2.8	0.7	1.3	0.7	0.6	0.6

Ce	9.4	5.6	2.3	5	1.7	2.7	0.8	0.7	
Pr	1.22	0.72	0.28	0.64	0.28	0.35	0.12	0.09	0
Nd	5.3	3.3	1.3	2.8	1.6	1.9	0.6	0.4	
Sm	1.43	0.88	0.42	0.78	0.75	0.76	0.21	0.11	0
Eu	0.57	0.53	0.2	0.3	0.44	0.45	0.17	0.12	0
Gd	1.89	1.43	0.82	1.12	1.28	1.12	0.43	0.33	0
Tb	0.36	0.26	0.18	0.22	0.26	0.22	0.08	0.08	0
Dy	2.22	1.66	1.37	1.53	1.67	1.35	0.52	0.7	0
Ho	0.47	0.37	0.34	0.32	0.31	0.29	0.11	0.17	0
Er	1.39	1.13	1.05	0.97	0.97	0.83	0.33	0.59	0
Tm	0.21	0.18	0.18	0.15	0.14	0.12	0.04	0.1	0
Yb	1.32	1.17	1.2	1.04	0.88	0.73	0.26	0.76	0
Lu	0.23	0.19	0.19	0.16	0.12	0.1	0.03	0.13	0
Y	13.3	11.2	8.8	8.8	8.7	7.6	2.9	5.3	

Table 6.Major element compositions (wt%) of siliceous rocks from Solonker ophiolite.

Sample	130930-11A	130928-05	130929-14	130929-15	130929-18
Rock type	Siliceous rocks	Siliceous rocks	Siliceous rocks	Siliceous rocks	Siliceous rocks
SiO2	85.47	70.35	79.86	71.09	88.44
Al2O3	5.97	15.68	10.81	14.1	4.03
TFe2O3	4.61	5.35	2.84	6.43	4.48
CaO	0.26	0.16	0.1	0.17	1.07
MgO	0.52	1.6	0.29	1.59	0.6
K2O	2	3.6	0.26	2.75	0.62
Na2O	0.01	2.21	5.46	2.84	0.02
MnO	0.693	0.109	0.045	0.105	0.374
TiO2	0.286	0.701	0.211	0.621	0.204
P2O5	0.047	0.083	0.022	0.057	0.085
LOI	0.01	0.02	0.01	0.03	0.02
Total	99.88	99.87	99.91	99.78	99.94

Table 7. Hf isotopic data of zircons from the gabbro samples of Solonker ophiolite.

Sample and spot analysis	¹⁷⁶ Hf/ ¹⁷⁷ Hf	1σ	¹⁷⁶ Lu/ ¹⁷⁷ Hf	1σ	¹⁷⁶ Yb/ ¹⁷⁷ Hf	1σ	Hf	Lu	Yb
Gabbro(130808-08)									
130808-08-1	0.282602	0.00001	0.002366	0.000024	0.066748	0.000943	56163.34174	141.5369216	926.1860602
130808-08-2	0.282672	0.000015	0.005385	0.000042	0.134999	0.001093	85728.00411	247.4365609	1450.870228
130808-08-3	0.282705	0.000018	0.002127	0.000038	0.055549	0.001222	34734.53588	94.41035689	568.9135083
Gabbro(SGZ-3)									
SGZ-3-1	0.282906	0.000014	0.001624	0.000049	0.035273	0.00117	25766.29706	83.38151444	419.5248361
SGZ-3-2	0.282618	0.000011	0.000861	0.000002	0.021277	0.000052	20147.99158	54.36439149	314.3722162
SGZ-3-3	0.282784	0.000011	0.000595	0.000004	0.013687	0.000101	14611.41248	39.58431324	212.6301492
SGZ-3-4	0.282467	0.000092	0.000574	0.000009	0.014318	0.000934	7097.651097	19.60410329	100.2924206
SGZ-3-5	0.282672	0.000013	0.000655	0.000005	0.013953	0.000184	10868.63194	31.74802015	159.5837013

Table 7. (Continued)

Age (Ma)	εHf(0)	1σ	εHf(t)	1σ	TDM1	TDM2	fLu/Hf
258.3	-6.021698119	0.623754703	-0.750919804	0.640799506	955.0496342	1194.813338	-0.928735096
258.9	-3.548286455	0.738253501	1.218589744	0.755911548	930.1362498	1085.767258	-0.83780437
260.4	-2.368401676	0.829730662	2.988677475	0.846198771	798.7354763	988.7721231	-0.93593632
261	4.732774866	0.711373171	10.19316514	0.73040753	498.9363867	587.3758933	-0.951072032
254	-5.447933737	0.642373659	-0.011752035	0.656671506	894.3315794	1150.509735	-0.974057547
257	0.43743492	0.638830603	5.986663082	0.65353817	655.6721286	819.1174346	-0.9820791
256	-10.79489359	3.278760679	-5.270144144	3.284928632	1097.769153	1443.518942	-0.982700828
255	-3.535394706	0.684995653	1.95819776	0.698896798	813.9460871	1041.856794	-0.980278097