The upper mantle section of the Cuobuzha ophiolite in the northern subbelt of the Yarlung Zangbo suture zone in southwest Tibet comprises merely clinopyroxene (cpx)-rich and depleted harzburgites. Spinel in the cpx-harzburgites display higher heavy rare earth element concentrations than the depleted harzburgites. The harzburgites have subchondritic Os isotopic compositions (0.11624–0.11699), whereas the cpx-harzburgites have supra-chondritic \( \text{\textsuperscript{187}}\text{Os}/\text{\textsuperscript{188}}\text{Os} \) ratios (0.12831–0.13125) with higher Re concentrations (0.380–0.575 ppb). Although these geochemical and isotopic signatures suggest that both peridotite types in the ophiolite represent mid-oceanic ridge-type upper mantle units, their melt evolution trends reflect different mantle processes. The cpx-harzburgites formed from low-degree partial melting of a primitive mantle source, and they were subsequently modified by melt-rock interactions in a mid-oceanic ridge environment. The depleted harzburgites, however, were produced by remelting of the cpx-harzburgites, which later interacted with mid-oceanic ridge basalt– or island-arc tholeiite–like melts, possibly in a trench–distal backarc spreading center. Our new isotopic and geochemical data from the Cuobuzha peridotites confirm that the Neo-Tethyan upper mantle had highly heterogeneous Os isotopic compositions as a result of multiple melt production and melt extraction events during its seafloor spreading evolution.

**INTRODUCTION**

Ophiolites are fragments of ancient oceanic lithosphere that have been emplaced onto continental margins, accretionary prisms, or island arcs during collisional and subduction-accretion events (Moore, 1982; Dilek and Robinson, 2003; Dilek and Furnes, 2011, 2014; Yang et al., 2014, 2015). The well-preserved peridotites within these ophiolites provide important information on melt extraction, partial melting, and melt-rock interaction within the upper mantle sections of the paleo-oceanic lithosphere (e.g., Dilek and Thy, 1998, 2009; Shallo and Dilek, 2003; Zhou et al., 2005; Arai et al., 2007; Dilek, 2007; Dai et al., 2011; Morishita et al., 2011; Uysal et al., 2012, 2015; Saka et al., 2014; Saccani et al., 2015; Niu et al., 2017). They display critical structural, petrological, and geochemical evidence for the processes that took place during oceanic lithosphere formation in different tectonic settings (e.g., Dilek and Newcomb, 2003; Pagé et al., 2009; Dilek and Furnes, 2014; Saccani et al., 2017).

The Yarlung Zangbo suture zone (YZSZ) in southern Tibet includes the remnants of Neo-Tethyan oceanic lithosphere and marks a major suture between the Indian plate to the south and the Lhasa terrane of Tibet to the north (Dupuis et al., 2005). The ophiolites within the YZSZ have been studied over the past 30 yr (Hébert et al., 2012, and references therein); however, their tectonic setting remains controversial in terms of whether they represent mid-oceanic ridge–generated oceanic lithosphere (Girardeau and Mercier, 1988; Nicolas, 1989) or the remnants of hydrous oceanic lithosphere that formed above an actively subducting slab in suprasubduction zone settings (Hébert et al., 2012). Recent field-based geochronological and geochemical studies along the YZSZ have shown that the internal structure of the suture zone is complex, with several distinct subbelts separated by continental fragments and showing different lithological, geochemical, and structural characteristics (Liu et al., 2015a, 2015b; Xu et al., 2015). In the western part of the YZSZ, the northern and the southern subbelts form two subparallel zones of mafic-ultramafic rock assemblages with overlapping crystallization ages (Wei et al., 2006; Xiong et al., 2011; Hebért et al., 2012; Liu et al., 2015a). A narrow sliver of deformed continental rocks occurs between these two subbelts within the YZSZ. The origin of this continental sliver and the potential genetic relationships between the different ophiolite massifs in these subbelts remain unknown (Liu et al., 2015b; Feng et al., 2015).

The Cuobuzha ophiolite in the northern subbelt includes an extensive upper mantle peridotite suite intruded by doleritic dikes and overlain by gabbros (Feng et al., 2015). Previous zircon laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) dating of these mafic dikes has yielded a crystallization age of 125.8 Ma (Liu et al., 2015b). This Early Cretaceous age of the mafic dikes provides a minimum time constraint for the formation of the Cuobuzha massif in the northern subbelt, and is compatible with the available crystallization ages from other ophiolite massifs in the southern subbelt, including the Dongbo (128 ± 1 Ma from gabbros; Xiong et al., 2011), Purang (130 ± 3 Ma from...
gabbros; Liu et al., 2011), and Xiugugabu (126–122 Ma from doleritic dikes; Wei et al., 2006). Although the available ages from both ophiolitic sub-belts reveal nearly coeval timing of oceanic crust formation, the mantle melt evolution and the isotopic features of the upper mantle peridotites exposed within the YZSZ are still poorly known.

In this paper we present new mineral chemistry, whole-rock major and trace element geochemistry, and Re-Os isotopic data from the Cuobuzha ophiolite, and discuss its mantle melt evolution within the framework of the Tethyan tectonics of the YZSZ. Our results and interpretations provide new insights and constraints for the heterogeneous nature of the Neo-Tethyan mantle, currently exposed along the >2000-km-long suture zone.

GEOLOGICAL SETTING

The YZSZ is the southernmost and the youngest of the sutures that divide the Tibetan Plateau into various east-west–oriented terranes (Fig. 1A). This suture extends discontinuously for nearly 2000 km and is divided into the eastern Qushui-Motuo and the central Angren-Rembu sections, and a western section from the west of Saga to the Sino-India boundary (Liu et al., 2015a). The latter is further divided into the northern Dajiweng-Saga and the southern Daba-Xiugugabu ophiolite sub-belts, which are separated by the Zhada-Zhongba continental suture. The southern part of the western YZSZ contains a series of well-preserved ophiolite massifs, including the Dongbo (~400 km²) and Purang (~600 km²) ophiolites (Xiong et al., 2011; Zhou et al., 2014; Liu et al., 2015a, 2015b; Niu et al., 2015). In comparison, the majority of the ophiolites within the northern subbelt are generally highly fragmented and altered, with a notable exception of the better preserved Dajiweng, Baer, Cuobuzha, Jianabeng, and Saga ophiolites (Liu et al., 2015b).

The northwest-southeast–trending Cuobuzha ophiolite crops out in the northern subbelt of the western YZSZ (Fig. 1B). It is predominantly made of upper mantle peridotites, composed of harzburgite and clinopyroxene (cpx)-harzburgite units with minor lenses and veins of dunite, which contain local occurrences of massive and disseminated chromitite. Massive chromitite is more common in these peridotites in comparison to the majority of the ophiolites within the northern Dajiweng-Saga and the southern Daba-Xiugugabu ophiolite sub-belts, which contain local occurrences of massive and disseminated chromitite (Liu et al., 2015b). In comparison, the majority of the ophiolites within the northern subbelt are generally highly fragmented and altered, with a notable exception of the better preserved Dajiweng, Baer, Cuobuzha, Jianabeng, and Saga ophiolites (Liu et al., 2015b).

PETROGRAPHY OF THE CUOBUZHA PERIDOTITES

As a tectonic block, the southern margin of the Cuobuzha massif (15 km in length, 0.2–0.5 km in width) was covered by Quaternary sediment, and the northern margin is unconformably contacted with the accretionary volcanic-sedimentary unit, which consists mainly of shale, alkaline basalt, siliceous rocks, siliceous limestone, and pyroclastic rocks. The hydrothermal metasomatic listwanite is 10–20 m in thickness overlying the Cuobuzha massif. We examined the dunite and harzburgite outcrops carefully in the field in order to document their contact relationships. We then systematically collected 13 harzburgite samples from the Cuobuzha ophiolite. Petrographic examination of thin sections provides detailed mineralogical and textural information on discrimination of the harzburgite and clinopyroxene (cpx)-harzburgite. It is difficult to distinguish these two groups of peridotites in the field.

The majority of the peridotite samples appear to have undergone only minor serpentinization. The depleted harzburgite consists mainly of olivine (55%–65%) and orthopyroxene (opx, 25%–35%) with minor amounts of cpx, spinel, and magnetite (Fig. 2A). The cpx-harzburgite contains olivine (55%–60%), opx (25%–35%), cpx (~3%), and minor amounts of spinel and magnetite (Fig. 2E). The opx grains in these peridotites occur as 8–10-mm-long porphyroblasts that are generally free of alteration (Fig. 2C); some opx porphyroblasts display kink banding and undulose extinction, indicating that they underwent large strain in lithospheric conditions (Fig. 2H). Larger opx crystals generally contain cpx exsolution lamellae and olivine inclusions (Fig. 2C). The spinel in these peridotites is present as an interstitial phase or as euhedral inclusions within olivine and opx grains (Figs. 2B, 2F).

ANALYTICAL TECHNIQUES

Mineral Chemistry

Major element compositions of the representative minerals were determined using a JXA-8100 electron microprobe at the Institute of Geology, Chinese Academy of Geological Sciences (Beijing, China). An accelerating voltage of 15 kV, a beam current of 1 × 10⁻⁸ A, and an electron beam diameter of 1 mm were utilized, and natural standards were used for calibration.

Whole-Rock Major and Trace Element Compositions

Whole-rock major and trace elements were analyzed at the China National Research Center of Geoanalysis, Chinese Academy of Geological Sciences (Beijing, China). Major element concentrations were determined on fused glass beads by X-ray fluorescence spectrometry, yielding an estimated analytical accuracy of 1% relative for SiO₂ and 2% relative for all other major elements. Trace elements, including the rare earth elements (REE), were determined by solution ICP-MS, with GB/T14506.28–2010 certified reference standards and three internal standards also measured simultaneously to ensure the consistency of the analytical results. Analytical uncertainties are estimated to be 10% for trace elements with concentrations of <10 ppm, and ~5% for elements with concentrations of >10 ppm.

Volatile concentrations were determined by gravimetric techniques whereby samples were heated in a closed container before the resulting water vapor was collected in a separate tube to be condensed and weighed.

Re-Os Isotopic Analysis

Re-Os isotopic measurements were done at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences (GIG-CAS) using rock samples that were first split into small chips using a hammer wrapped in paper to avoid contamination. Some 0.5–0.6 g of finely powdered sample was spiked with ¹⁸⁶Os and ¹⁸⁷Re prior to freezing with 2 mL of concentrated HCl and 6 mL of concentrated HNO₃ in a Carus tube. The samples were then sealed and heated to 240 °C for 24 h (Shirey and Walker, 1998). Carbon tetrachloride was subsequently added to the acid mixture before Os was extracted from the aqueous phase (Pearson and Woodland, 2000), with the resulting Os purified by microdistillation. Re was separated and purified by anion exchange using AG1X8 resin (100–200 mesh). Isotope abundances in OsO₂ and ReO₃ were determined using a Thermo Finnigan TRITON mass spectrometer in negative ion detection mode (Völkering et al., 1991), equipped with an oxygen gas leak valve and an ion counting multiplier. Os was loaded onto a high-purity Pt filament (manufactured by H. Cross Co., Ltd.; 99.999% purity, 1 × 0.025 mm) that had been heated in air for ~3 min. The resulting Re and Os isotope compositions were measured using a static multiple Faraday collector and a pulse-counting electron multiplier, respectively. The instrumental mass fractionation of Os was corrected by normalizing measured ¹⁸⁶Os/¹⁸⁷Os ratios to 3.08271 (Nier, 1937), with Re isotopes measured using a total...
Figure 1. (A) Distribution of the ophiolites along the Yarlung Zangbo suture zone (TZSZ) and Bangong-Nujiang suture zone in Tibet. (B) Simplified geological map of the ophiolites in the western part of the YZSZ (after Liu et al., 2015a). (C) Simplified geological map of the study area and surrounding region with sampling locations (after Liu et al., 2015b).
Figure 2. Photomicrographs of representative samples from the study area. (A) Harzburgite, interstitial structure, with spinel filling in the interval of olivine (ol) and orthopyroxene (opx; cross-polarized light, sample 12Y-C-1–2). (B) Black spinel (spl) within harzburgite (cross-polarized light, sample 12Y-C-2–1). (C) Harzburgite containing porphyroblasts, olivine with peritectic texture, and coarse kinked orthopyroxene grains with clinopyroxene exsolution lamellae (cross-polarized light, sample 12Y-C-3–1). (D) Orthopyroxene porphyroblast embayed by olivine (cross-polarized light, sample 12Y-C-5–1). (E) Clinopyroxene (cpx) harzburgite (cross-polarized light, sample 12Y-C-9–2). (F) Brown vermicular spinels in cpx-harzburgite (plane-polarized light, sample 12Y-C-11–2). (G) Harzburgite containing anhedral spinel and clinopyroxene with olivine and orthopyroxene porphyroblasts (backscattered electron, BSE, image of a polished thin section, sample 12Y-C-5–3). (H) Exsolution lamellae of clinopyroxene in deformed orthopyroxene (BSE image, sample 12Y-C-11–3). (I) Primary euhedral spinels in chromitite (BSE images, sample 12Y-C-23–5).
TABLE 1. RESULTS OF ELECTRON MICROPROBE ANALYSES OF OLIVINE IN THE CUOBUZHA PERIDOTITES

| Mineral | 12YC-1 | 12YC-2 | 12YC-3 | 12YC-4 | 12YC-5 |
|---------|--------|--------|--------|--------|--------|
| MgO    | 49.6   | 47.3   | 47.1   | 48.3   | 45.8   |
| SiO2   | 55.52  | 54.92  | 55.34  | 55.16  | 56.48  |
| Na2O   | 0.04   | 0.03   | 0.02   | 0.05   | 0.01   |
| Cr2O3  | 0.55   | 0.53   | 0.49   | 0.63   | 0.25   |
| K2O    | 0.02   | 0.01   | 0.01   | 0.02   | 0.00   |
| Mgo    | 34.39  | 34.00  | 33.79  | 33.58  | 32.97  |
| Al2O3  | 5.00   | 0.00   | 0.00   | 0.02   | 0.01   |
| MnO    | 0.11   | 0.09   | 0.12   | 0.10   | 0.14   |
| FeO    | 0.02   | 0.01   | 0.01   | 0.02   | 0.02   |
| NiO    | 0.35   | 0.33   | 0.35   | 0.33   | 0.36   |
| Total  | 99.74  | 99.27  | 99.91  | 99.39  | 99.84  |
| Fo     | 91     | 90     | 90     | 90     | 90     |

Note: n—number of analyses; forsterite, Fo = 100 × molar Mg/(Fe + Mg). Cpx—clinopyroxene. Data for 12YC-1, 12YC-3, 12YC-4, and 12YC-5 are from Feng et al. (2015).

TABLE 2. RESULTS OF ELECTRON MICROPROBE ANALYSES OF ORTHOPYROXENE IN THE CUOBUZHA PERIDOTITES

| Mineral | 12YC-1 | 12YC-3 | 12YC-9 | 12YC-10 | 12YC-11 | 12YC-13 |
|---------|--------|--------|--------|---------|---------|---------|
| MgO    | 32.35  | 31.64  | 31.64  | 31.64   | 31.64   | 31.64   |
| SiO2   | 55.18  | 54.92  | 54.92  | 54.92   | 54.92   | 54.92   |
| Na2O   | 0.25   | 0.32   | 0.38   | 0.46    | 0.41    | 0.37    |
| Cr2O3  | 0.32   | 0.32   | 0.32   | 0.32    | 0.32    | 0.32    |
| K2O    | 0.04   | 0.01   | 0.01   | 0.02    | 0.00    | 0.00    |
| Mgo    | 34.72  | 34.72  | 34.72  | 34.72   | 34.72   | 34.72   |
| Al2O3  | 3.00   | 3.00   | 3.00   | 3.00    | 3.00    | 3.00    |
| MnO    | 0.10   | 0.10   | 0.10   | 0.10    | 0.10    | 0.10    |
| FeO    | 0.16   | 0.16   | 0.16   | 0.16    | 0.16    | 0.16    |
| NiO    | 0.02   | 0.02   | 0.02   | 0.02    | 0.02    | 0.02    |
| Total  | 99.27  | 99.27  | 99.27  | 99.27   | 99.27   | 99.27   |
| Fo     | 90     | 90     | 90     | 90      | 90      | 90      |

Note: n—number of analyses; forsterite, Fo = 100 × molar Mg/(Fe + Mg). Cpx—clinopyroxene. Data for 12YC-1, 12YC-3, 12YC-9, 12YC-10, 12YC-11, and 12YC-13 are from Feng et al. (2015).

TABLE 3. RESULTS OF ELECTRON MICROPROBE ANALYSES OF CLINOPYROXENE IN THE CUOBUZHA PERIDOTITES

| Mineral | 12YC-1 | 12YC-3 | 12YC-4 | 12YC-5 |
|---------|--------|--------|--------|--------|
| MgO    | 49.6   | 47.3   | 47.1   | 48.3   |
| SiO2   | 55.52  | 54.92  | 55.34  | 55.16  |
| Na2O   | 0.04   | 0.03   | 0.02   | 0.05   |
| Cr2O3  | 0.55   | 0.53   | 0.49   | 0.63   |
| K2O    | 0.02   | 0.01   | 0.01   | 0.02   |
| Mgo    | 34.39  | 34.00  | 33.79  | 33.58  |
| Al2O3  | 5.00   | 0.00   | 0.00   | 0.02   |
| MnO    | 0.11   | 0.09   | 0.12   | 0.10   |
| FeO    | 0.02   | 0.01   | 0.01   | 0.02   |
| NiO    | 0.35   | 0.33   | 0.35   | 0.33   |
| Total  | 99.74  | 99.27  | 99.91  | 99.39  |
| Fo     | 91     | 90     | 90     | 90     |

Note: n—number of analyses; forsterite, Fo = 100 × molar Mg/(Fe + Mg). Cpx—clinopyroxene. Data for 12YC-1, 12YC-3, 12YC-4, and 12YC-5 are from Feng et al. (2015).
in the harzburgite samples (0.10–0.23 wt%). Spinel NiO concentrations systematically decrease from the cpx-harzburgites (0.27–0.30 wt%) to the harzburgites (0.15–0.20 wt%).

**WHOLE-ROCK GEOCHEMISTRY**

**Major Oxide and Trace Element Data**

The major and trace element compositions of the Cuobuzha peridotites are given in Table 5. All of the samples underwent variable degrees of serpentinization, as evidenced by the loss on ignition values (0.76–6.59 wt%). The influence of serpentinization effects in our samples was removed by recalculating all concentrations to a 100% anhydrous basis, yielding the values discussed in the following.

The harzburgite and cpx-harzburgite samples have distinct chemical compositions, with the former containing lower concentrations of Al₂O₃ and CaO (1.19–1.67 and 0.95–1.85 wt%, respectively) than the latter (2.41–2.77 and 2.34–3.05 wt%, respectively), correlating with the cpx abundance in these samples. Most of the peridotites are enriched in the transition elements that are compatible in ultramafic rocks (Ni = 1956–2247 ppm, Cr = 1697–2822 ppm) compared to the primitive mantle (Ni = 1860 ppm, Cr = 2520 ppm; Palme and O’Neill, 2003). Both rock types have similar whole-rock Mg# values (91–92), although the harzburgites contain higher concentrations of MgO (41.03–43.83 wt%) than the cpx-harzburgites (39.29–40.84 wt%). These concentrations can be used as an indicator of the degree of depletion, with increases in MgO correlating with increased depletion and increased olivine abundance. The most effective approach to examining the chemical changes in our peridotite samples is to compare the concentrations of elements of interest with MgO concentrations. Both rock types have negative correlations between SiO₂, Al₂O₃, and CaO with MgO. Figure 3 compares the Cuobuzha peridotites with abyssal (or mid-ocean ridge type) and suprasubduction zone (SSZ) type peridotites. The Cuobuzha peridotites are more similar to mid-ocean ridge type than SSZ type, similar to the compositions of peridotites from the Purang (Zhou et al., 2014) and Dongbo (Niu et al., 2015) ophiolites within the southern subbelt and the Daijiezhong ophiolite (Lian et al., 2014) in the northern subbelt of the YZSZ.

The upper mantle peridotites within the Cuobuzha ophiolite have total REE (SREE) concentrations of 0.30–1.63 ppm that are well below the primitive mantle concentrations, indicating significant degrees of depletion, presumably as a result of variable degrees of partial melting (Miller et al., 2003). All of these peridotites have REE patterns that are increasingly depleting between Lu and Pr but are slightly enriched in Ce and La (Fig. 4A). The harzburgite samples are more depleted in the heavy (H) REEs than the cpx-harzburgites, and have a shallow slope between the HREEs and the medium (M) REEs. However, all of the Cuobuzha peridotites have similar light (L) REE concentrations. In addition, one harzburgite sample (12YC-6) contains lower HREE contents than the other samples, although its MREE and LREE values are similar to those of the other samples. Our peridotite samples also have similar primitive mantle–normalized variation patterns (Fig. 4B), showing enrichment in both the large ion lithophile elements (LILE; Rb and Sr) and the high field strength elements (HFSE; Ta, Hf, and Ti). The more depleted HREE patterns of Sample 12YC-6 indicate higher degrees of partial melting than the other samples (Fig. 4).

**Os Isotope Data**

The Os isotope compositions of the Cuobuzha peridotites are given in Table 6. The harzburgite and cpx-harzburgite samples contain Re concentrations of 0.080–0.575 and 0.380–0.575 ppb, respectively. The harzburgites have subchondritic Os isotopic compositions (0.11624–0.11699) compared with the carbonaceous chondrite ratio of 0.127 (Shirey and Walker, 1998). In contrast, the cpx-harzburgites have suprachondritic ¹⁸⁷Os/¹⁸⁸Os ratios (0.12831–0.13125; Fig. 5A) that are similar to the values for peridotites in other ophiolites, including the Purang (also named as Yungbwa) (¹⁸⁷Os/¹⁸⁸Os ratios of 0.1223–0.1313; Miller et al., 2003; Liu et al., 2012) and Troodos (0.1291–0.1390; Büchel et al., 2002) peridotites. The Os concentrations of the Cuobuzha peridotites (3.897–7.693 ppb) are higher than the Os concentrations within any possible metasomatic agents (0.100 ppb; Dale et al., 2007), suggesting that the Re-Os system within the Cuobuzha peridotites was not contaminated subsequently. In addition, these peridotites have low Re/Os ratios (0.010–0.136; Table 6) and a negligible age correction for isotopic growth since the time of formation. As such, the Os isotope data presented here most likely reflect the primary Os compositions of the Cuobuzha peridotites.

**DISCUSSION**

**Degrees of Partial Melting and Implications**

Experimental studies have shown that the equilibrium between olivine and melt remains unchanged by the addition of H₂O to the system (Gaetani and Grove, 1998), suggesting that olivine Fo compositions are indicative of the total degree of partial melting undergone by upper mantle peridotites (Uysal et al., 2012). Given that the Cuobuzha peridotites contain olivine with high Fo contents (89.1–91.4), their compositions reflect different degrees of partial melting. In addition, the Cr# and Mg# values of the spinels within these peridotites show a negative correlation, providing more evidence that these rocks were produced by different degrees of partial melting (Fig. 6A). The spinel Cr# values and olivine Fo compositions for these peridotites plot along the olivine-spinel mantle array (Arai, 1994; Fig. 6B), confirming that the Cuobuzha peridotites represent the residues after variable degrees of melt extraction. The cpx-harzburgites represent the residues after low-degree partial melting (~5%), whereas the depleted harzburgites represent the residues after higher degrees of partial melting (10%–17%). In general, the LREE and the MREE values are moderately affected by mantle metasomatism effects, but HREE abundances are commonly less affected by post-melt extraction metasomatism (Bodinier et al., 1988). Therefore, we have applied modeling
| Major elements (wt%) | Silicates | AL2O3 | CaO | TFe2O3 | K2O | MgO | SiO2 | TiO2 | Mg# | MgO | Ti | P2O5 | CaO | K2O | Ni | Lu | ΣREE | Rb | Ta | Y | La/N | Yb | Lu/N | Ho | Tb | Er | Tb | Pr | Nd | Tb | Ho | Tb/N | Pr/N | Nd/N | Eu | Pr/Eu | Tb/Eu | Gd | Gd/Eu | Yb/Eu | Lu/Eu | Ho/Eu | Tb/Eu | HREE/LREE | REE/LREE | REE/HREE | REE/LREE | REE/HREE | REE/LREE |
|---------------------|----------|------|-----|--------|------|-----|------|------|-----|-----|-----|-----|------|-----|-----|----|----|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| MgO                 | 45.27    | 45.13| 45.23| 44.78 | 44.85| 46.31| 44.17| 44.72| 45.45| 45.45| 45.45| 45.93| 44.30|
| Al2O3               | 1.67     | 1.40 | 1.33 | 1.35  | 1.35 | 1.21 | 1.19 | 1.16 | 2.66  | 2.41 | 2.60  | 2.77 | 2.59 |
| CaO                 | 1.85     | 0.95 | 1.00 | 1.35  | 1.40 | 0.95 | 1.73 | 0.97 | 2.82  | 2.34 | 2.54  | 3.05 | 2.81 |
| TFe2O3              | 8.84     | 8.64 | 8.72 | 9.19  | 8.98 | 8.05 | 9.40 | 8.98 | 8.84  | 8.99 | 8.73  | 8.86 | 8.70 |
| K2O                 | 0.02     | 0.02 | 0.02 | 0.02  | 0.01 | 0.01 | 0.01 | 0.01 | 0.01  | 0.01 | 0.01  | 0.01 | 0.02 |
| MgO                 | 41.03    | 42.58| 43.01| 43.16 | 42.74| 43.15| 43.83| 42.54| 39.50 | 40.84| 39.81 | 39.29| 40.29|
| MnO                 | 0.13     | 0.13 | 0.12 | 0.13  | 0.13 | 0.12 | 0.13 | 0.13 | 0.12  | 0.13 | 0.12  | 0.12 | 0.12 |
| Na2O                | 0.09     | 0.05 | 0.07 | 0.05  | 0.07 | 0.05 | 0.07 | 0.05 | 0.11  | 0.06 | 0.07  | 0.11 | 0.20 |
| P2O5                | 0.02     | 0.01 | 0.01 | 0.01  | 0.01 | 0.01 | 0.01 | 0.01 | 0.01  | 0.01 | 0.01  | 0.01 | 0.01 |
| TiO2                | 0.06     | 0.08 | 0.08 | 0.05  | 0.10 | 0.02 | 0.04 | 0.06 | 0.05  | 0.06 | 0.05  | 0.07 | 0.06 |
| LOI                 | 3.99     | 5.55 | 5.41 | 4.54  | 5.79 | 6.55 | 6.59 | 5.94 | 3.8   | 0.76 | 2.34  | 1.5   | 1.56 |
| Total               | 98.99    | 99.00| 99.6 | 100.09| 99.64| 99.88| 100.59| 99.09| 99.58  | 100.3| 99.39 | 100.22| 99.11|
| Mg#                 | 91       | 92   | 92   | 91    | 92   | 91   | 91    | 91    | 91     | 91   | 91    | 91    | 91    |

**Note:** Mg# = 100 × molar Mg/(Mg + ∑Fe); iEu = EuN /√(SmN × GdN). T—total; LOI—loss on ignition; REE—rare earth element; L—light; H—heavy. Harzburgite data are from Feng et al. (2015).
Figure 3. Variations in whole-rock major element concentrations relative to MgO within peridotite samples from the Cuobuzha (CBZ) ophiolite. Compositions are recalculated on a volatile-free basis. The abyssal and suprasubduction zone (SSZ; cpx—clinopyroxene) peridotite fields are from Niu et al. (1997) and Parkinson and Pearce (1998), respectively, and data for other peridotites are from the Purang (Zhou et al., 2014), Dongbo (Niu et al., 2015), and Dajiweng (Lian et al., 2014) ophiolites.
Figure 4. (A) Chondrite-normalized rare earth element (REE) patterns for samples of the Cuobuzha (CBZ) peridotites normalized to the chondrite composition of McDonough and Sun (1995). (B) Primitive mantle–normalized multi-element patterns for peridotites from the study area. Also shown are the REE compositions of Izu-Bonin forearc basin peridotites (Parkinson and Pearce, 1998) and normal mid-oceanic ridge basalt (N-MORB)-like mantle sources (Salters and Stracke, 2004), with dashed lines indicating modeled peridotite compositions at 5%, 10%, 15%, 20%, 25%, and 30% partial melting (after Dupuis et al., 2005) (cpx—clinopyroxene).

Figure 5. (A) Whole-rock $^{187}$Re/$^{188}$Os versus $^{187}$Os/$^{188}$Os of selected peridotite samples. (B) $\text{Al}_2\text{O}_3$ (WR—whole rock; cpx—clinopyroxene) versus Re compositions of selected peridotite samples. The depletion trend in B shows the results of dynamic melting of primitive mantle material (with 1% porosity) using the partition coefficients of Adam and Green (2006) and Batanova et al. (2008).

**Table 6. Re-Os isotopic data for analyzed samples of the Cuobuzha peridotites**

| Sample | Rock type | Re (ppb) | 2SE | Os (ppb) | 2SE | Re/Os | $^{187}$Os/$^{188}$Os | 2SE | $^{187}$Re/$^{188}$Os | 2SE | $\text{Tu}_\text{m}/\text{Ga}$ | $\text{TD}_\text{m}/\text{Ga}$ |
|--------|-----------|----------|-----|----------|-----|-------|-----------------|-----|-----------------|-----|----------------|----------------|
| 12YC-1 Hz | 0.080  | 0.007 | 7.693 | 0.227 | 0.010 | 0.11624 | 0.00026 | 0.05 | 0.00 | 2.0559 | 1.8217 |
| 12YC-3 Hz | 0.140  | 0.009 | 5.579 | 0.369 | 0.025 | 0.11673 | 0.00042 | 0.12 | 0.01 | 2.4177 | 1.7567 |
| 12YC-4 Hz | 0.103  | 0.010 | 4.630 | 0.043 | 0.022 | 0.11699 | 0.00014 | 0.11 | 0.01 | 2.2743 | 1.7216 |
| 12YC-10 Cpx-Hz | 0.380 | 0.008 | 5.029 | 0.144 | 0.076 | 0.13041 | 0.00022 | 0.36 | 0.01 | f | f |
| 12YC-12 Cpx-Hz | 0.530 | 0.016 | 3.897 | 0.087 | 0.136 | 0.13125 | 0.00036 | 0.65 | 0.03 | 0.4497 | f | f |
| 12YC-13 Cpx-Hz | 0.575 | 0.020 | 5.214 | 0.051 | 0.110 | 0.12831 | 0.00014 | 0.53 | 0.02 | f | f |

Note: Hz—Harzburgite; Cpx—clinopyroxene; f—future; SE—standard error. Both isotope ratios and Re-Os concentrations are corrected for blanks. Re = 1.666 $\times 10^{-11}$/yr (Smoliar et al., 1996). $\text{Tu}_\text{m}$ (mantle model ages) and $\text{TD}_\text{m}$ (Re-depletion model ages) are calculated relative to the primitive upper mantle using the primitive upper mantle Re-Os isotope composition of Meisel et al. (2001b), where $^{187}$Os/$^{188}$Os = 0.1296 and $^{187}$Re/$^{188}$Os = 0.4346.
of the HREE values in our samples, and obtained similar results, with partial melting degrees increasing from the cpx-harzburgites (5%–8%) to the harzburgites (15%–17%; Fig. 4A).

**Oxygen Fugacity and Tectonic Setting**

It is generally accepted that mantle wedge peridotites above subduction zones are more oxidized than upper mantle peridotites in other tectonic settings (e.g., Parkinson and Arculus, 1999). Plotting peridotite compositions in a V versus Yb diagram can provide insights into oxygen fugacity (fO2) conditions, which are particularly useful because depletion trends are strongly dependent on fO2 conditions (Pearce and Parkinson, 1993). The relatively reducing conditions that are characteristic of abyssal peridotite formation (e.g., fayalite-magnetite-quartz, FMQ–1) yield high V3+/V4+ values, consistent with low partition coefficients. The resulting mantle residues are therefore relatively undepleted in V at a given degree of partial melting. In contrast, the relatively oxidizing conditions that are characteristic of the formation of SSZ peridotites (e.g., FMQ+1) are associated with low V3+/V4+ values and high partition coefficients, leading to rapid depletion of V in the mantle residue and a steeper depletion trend in the V versus Yb diagram. All the cpx-harzburgite samples plot between the FMQ and FMQ–1 trends in Figure 7A, whereas most of the harzburgite samples plot close to the FMQ trend (Fig. 7A). All of these samples plot in the same field of the V versus MgO diagram (Fig. 7B), with half of the depleted harzburgite samples plotting between FMQ and FMQ+1 trends. We attribute the wide range of oxygen fugacities to low Cr# of the spinel compositions in our peridotite samples to fluid-rock interactions (Aldanmaz et al., 2009).

These observations and findings indicate that the Cuobuzha peridotites were the products of low-degree partial melting in a mid-oceanic ridge environment. The depleted harzburgites were most likely derived from remelting of the cpx-harzburgite rocks, and some of the peridotite samples that plot between the FMQ and FMQ+1 trends may have resulted from fluid-rock interactions following the formation of the harzburgites.

**Melt-Peridotite Interaction**

Conventionally, cpx-harzburgites and harzburgites are thought to represent depleted refractory residues produced by partial melting of the mantle (e.g., Himmelberg and Loney, 1973). However, the Cuobuzha peridotites are also LREE enriched and have high LREE/MREE ratios, indicating that these upper mantle rocks could not just have formed as residual material after partial melting of the primitive mantle (e.g., Frey et al., 1991). They also have LILE (Rb and Sr) enriched primitive mantle–normalized multielement variation patterns (Fig. 4B). They plot away from partial melting curves in an Al2O3 (cpx) versus TiO2 (cpx) diagram (Fig. 8A), as a result of elevated concentrations of TiO2 in their cpx. These observations strongly suggest that the Cuobuzha peridotites were not generated by simple partial melting processes.

One possible explanation for the unusual compositions of these upper mantle peridotites is melt-rock interactions (Sharma and Wasserburg, 1996). However, these peridotites also show HFSE (Ta, Hf, and Ti) enrichments in primitive mantle–normalized multielement variation diagrams, and these elements are commonly considered immobile during low-temperature alteration (Fig. 4B; Dai et al., 2011). These patterns strongly suggest that the Cuobuzha peridotites record variations in their partial melting degrees as well as variable melt-rock interaction effects, as observed in other ophiolitic mantle peridotites (e.g., Zhou et al., 2005; Morishita et al., 2011; Uysal et al., 2012; Wu et al., 2017). Mineralogical and textural evidence for melt-rock interactions is provided by the presence of embayments in opx that are filled with olivine (Fig. 2D) and by the presence of vermicular spinel in our peridotite samples (Fig. 2F).

In terms of melt-rock interaction processes, the trends in Figure 8B demonstrate clear differences between the harzburgite and cpx-harzburgite samples. The cpx-harzburgite samples plot close to a partial melting trend, whereas the depleted harzburgite samples define a trend between the mid-oceanic ridge basalt (MORB) and island-arc tholeiite (IAT) spinel compositions, such as those documented from the Scotia Sea and the Lau Basin. The incompatible element enrichments observed for the Cuobuzha

**Figure 6.** (A) Cr# versus Mg# diagram for spinels (Spl) (after Uysal et al., 2015). The fields for spinels within abyssal peridotites, normal mid-oceanic ridge basalt (N-MORB), and boninites are from Dick and Bullen (1984); the field for spinel in forearc peridotites is from Parkinson and Pearce (1998), and the fields for spinels in island-arc tholeiites and backarc basin basalts are from Allan (1994). The arrow with ticks and percentages indicates the percentage of melting of the host peridotite (Arai, 1992). IAT — island-arc tholeiite; SSZ—suprasubduction zone; Cpx—clinopyroxene. (B) Spinell Cr# values versus forsterite (Fo) contents of coexisting olivine (Ol) (Arai, 1992) in peridotite samples from the study area. Fields for passive margin, abyssal, and forearc peridotites are from Dick and Bullen (1984), Arai (1994), and Parkinson and Pearce (1998). FMM = fertile mid-oceanic ridge–type mantle.
Figure 7. (A) Whole-rock Yb-V diagram showing modeled variations in the degree of partial melting and oxygen fugacities ($f_{O_2}$) for peridotite samples from the Cuobuzha peridotites, following the approach outlined by Pearce and Parkinson (1993). The lines indicate fractional melting trends under different $f_{O_2}$ conditions, with each point on each line representing a change of 5% in the degree of partial melting. FMQ—fayalite-magnetite-quartz; FMM—fertile mid-oceanic ridge basalt. (B) Whole-rock V versus MgO diagram for samples from the study area (after Uysal et al., 2012). Partial melting curves are shown at 1 log unit intervals, spanning $f_{O_2}$ conditions between FMQ–3 and FMQ+2. The dashed line represents unbuffered fractional melting in which $f_{O_2}$ is initially set to FMQ but is allowed to evolve with progressive melting in a system closed to O$_2$ exchange. The dotted vertical lines represent the degree of melt extraction in 10% increments (Lee et al., 2003). Oceanic mantle data are from Bodinier (1988). Cpx—clinopyroxene.

Figure 8. (A) Whole-rock TiO$_2$ versus Al$_2$O$_3$ diagram for clinopyroxene in peridotite samples of the present study. The fields for clinopyroxene (Cpx) within passive margin, abyssal, and forearc peridotites are from Dick and Bullen (1984), Arai (1994), and Parkinson and Pearce (1998). SSZ—suprasubduction zone. (B) Cr# versus TiO$_2$ diagram for spinels (Spl) within samples from the study area (modified from Pearce et al., 2000). This diagram discriminates between partial melting trends (modeled) and melt-mantle interaction trends (drawn empirically). FMM—fertile mid-oceanic ridge basalt (MORB) mantle, IBM—Izu-Bonin-Mariana. Subscripts m, I, and b refer to arc-basin basalt-hosted spinel compositions in MORB, island-arc tholeiite (IAT), and boninite (BON) settings, respectively.
cpx-harzburgites may have been caused by melt-rock interactions following a partial melting episode in a mid-oceanic ridge setting. In contrast, the Cuobuza harzburgites most likely formed as a result of interactions between a cpx-harzburgite residual mantle material and MORB melts or melts with MORB to IAT compositions beneath a seafloor spreading axis.

**Re-Os Constraints on Provenance and Mantle Processes**

Re behaves moderately incompatibly and Os behaves compatibly during partial melting so that partial melting lowers Re/Os ratios and reduces the increase of $^{187}$Os/$^{188}$Os values with time (Büchel et al., 2004). Subchondritic $^{187}$Os/$^{188}$Os ratios are thus most likely the result of ancient episodes of partial melting (Büchel et al., 2004). The Cuobuza harzburgites have subchondritic Os isotopic compositions, yielding Re-depletion model ages ($T_{\text{Re}}$) ages from 1.8 to 1.7 Ga (Table 6), indicating that the Cubuza mantle underwent at least one ancient melt extraction event ca. 1.8–1.7 Ga. The Cuobuza mantle had therefore undergone partial melting long before the Cuobuza ophiolitic crust was developed. It was discussed that ancient depletion events recorded by Os isotopes can be preserved in the convecting upper mantle for several billion years (Liu et al., 2012).

The cpx-harzburgites within the Cuobuza ophiolite have chondritic or suprachondritic Os isotopic compositions, which yield future $T_{\text{Re}}$ ages. As the elements Re and Al behave in a moderately incompatible fashion during partial melting, the concentrations of these elements in the partial melting residue of the upper mantle are expected to correlate with each other (Zheng et al., 2009; Uysal et al., 2015). However, the Re content of our samples does not show any correlation with the Al$_2$O$_3$ contents, and all three cpx-harzburgite samples have elevated Re concentrations (0.380–0.575 ppb) relative to the primitive mantle (0.28 ppb; Meisel et al., 2001a, 2001b) that cannot be explained by simple melt extraction and depletion. Instead, these findings strongly suggest late-stage addition of Re into the cpx-harzburgites (Uysal et al., 2012). The cpx-harzburgites plot in an Re versus Al$_2$O$_3$ diagram (Fig. 5B) as a result of subsequent addition of Re following the last partial melting event that occurred during mid-oceanic ridge melt evolution processes (Uysal et al., 2015).

Büchel et al. (2002, 2004) argued that primary Os can be removed from mantle peridotites by percolating melts at high melt/rock ratios, causing primary sulfides to be scavenged by these melts, and secondary sulfides to be desegregated from the melt and deposited in the upper mantle peridotites. This process can also produce reactive peridotites with suprachondritic Pd/Ir and Re/Ir ratios (Liu et al., 2012). The two types of Cuobuza peridotites have similar Ir-group PGE contents (Feng et al., 2016), and the cpx-harzburgites have higher Pd (4.67–8.56 ppb) and Re (0.380–0.575 ppb) values than those of the harzburgites (Pd = 1.32–5.09 ppb; Re = 0.080–0.140 ppb). The much higher Pd/Ir and Re/Ir ratios of the cpx-harzburgites suggest that the suprachondritic Os isotopic ratios within the Cuobuza cpx-harzburgites may have resulted from melt percolation processes whereby the melts removed sulfides from the mantle rocks but transferred their Os isotopic signature into the Cuobuza upper mantle.

The two Cuobuza peridotite types record different mantle processes. The cpx-harzburgites were first generated by low degrees of partial melting. They subsequently underwent melt-rock interactions during which the percolating melts removed their sulfides and transferred their $^{187}$Os/$^{188}$Os signature to the mantle. The harzburgites are the products of high degrees of partial melting of the cpx-harzburgites. We infer that both partial melting events and the melt-rock interactions might have taken place beneath a trench–distal backarc basin spreading center with little or no subduction influence. This interpretation is also consistent with the recent geodynamic models explaining the tectonic and magmatic evolution of the Tibetan Neo-Tethys and the YZSZ ophiolites in a regional framework (Hébert et al., 2012).

**Tectonic Implications**

Our results suggest that the cpx-harzburgites underwent Re addition after an initial partial melting episode of the mantle source. Therefore, we have instead used the harzburgites to evaluate the mantle source properties. In the southern subbelt of the western YZSZ, the Dongbo peridotites have $^{187}$Os/$^{188}$Os values of 0.1235–0.1282 and $T_{\text{Re}}$ ages of 0.22–0.96 Ga (Niu et al., 2015), whereas the Purang peridotites in the same subbelt have $^{187}$Os/$^{188}$Os values of 0.1228–0.1286 (Liu et al., 2012) and $T_{\text{Re}}$ ages of 0.1–1.0 Ga. Combining these extant data with our data from the Cuobuza harzburgites in the northern subbelt (with lower $^{187}$Os/$^{188}$Os values of 0.11624–0.11699 and older $T_{\text{Re}}$ ages of 1.7–1.8 Ga), we find out that the Neo-Tethyan mantle, now exposed along the YZSZ, had highly heterogeneous Os isotopic compositions (Parkinson et al., 1998; Walker et al., 2005). The older than 1.0 Ga depletion events were clearly very important for the evolution of the upper mantle beneath the northern subbelt. The modal ages younger than 1.0 Ga recorded by the peridotites in the Southern subbelt may correspond to a series of depletion events related to the opening of the Proto-Tethys and Neo-Tethys ocean basins (Uysal et al., 2012). More detailed research on the Re-Os isotope systematics of the YZSZ peridotites should reveal critical insights into better understanding of the nature and distribution of the YZSZ mantle heterogeneities beneath this suture zone and the southern Tibetan orogenic belt.

**CONCLUSIONS**

The Cuobuza upper mantle section in the northern subbelt of the western YZSZ contains cpx-harzburgites and depleted harzburgites that collectively display textural, mineralogical, whole-rock geochemical, and isotopic evidence for two stages of partial melting and refertilization processes during the evolution of the Neo-Tethyan mantle. The cpx-harzburgites resulted from low-degree partial melting (~5%) prior to their modification by melt percolation processes beneath a seafloor spreading center. The percolating melts removed mantle sulfides and gave these peridotites a melt-like $^{187}$Os/$^{188}$Os signature. In comparison, the depleted harzburgites underwent higher degrees of partial melting. They represent residual peridotites after remelting of the cpx-harzburgites and their interactions with MORB- or IAT-type melts. Comparison of the upper mantle peridotites in the two subbelts of the western YZSZ suggests that the Neo-Tethyan mantle had highly heterogeneous Os isotopic compositions.

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**REFERENCES CITED**

Adam, J., and Green, T., 2006, Trace element partitioning between mica- and amphibole-bearing garnet harzburgite and hydrous basaltic melt: Experimental results and the investigation of controls on partitioning behavior: Contributions to Mineralogy and Petrology, v. 152, p. 1–17, doi:10.1007/s00410-005-0298-4.

Aldanmaz, E., Schmidt, M.W., Gourauda, S., and Meisel, T., 2009, Mid-ocean ridge and supra-subduction geochemical signatures in spinel-peridotites from the Neotethys ophiolites in SW Turkey: Implications for upper mantle melting processes: Lithos, v. 113, p. 691–708, doi:10.1016/j.lithos.2009.03.010.

Allan, J.F., 1994, Cr-spinel in deformed basalts from the Lau basin back-arc: Petrogenetic history from Mg-Fe crystal-liquid exchange, in Hawkins, J., et al., eds., Proceedings of the Ocean Drilling Program, Scientific Results, Volume 135: College Station, Texas, Ocean Drilling Program p. 565–568, doi:10.2973/odp.proc.v.135.138.1994.
Arai, S., Abe, N., and Ishimaru, S., 2007, Mantle peridotites from the western Pacific: Gondwanan affinity and melting history. Gondwana Research, v. 11, p. 49–56, doi: 10.1016/j.gr.2006.04.004.

Batanova, G.V., Brügmann, G.E., Baizyev, B.A., Sobolev, A.V., Kamenetsky, V.S., and Hofmann, A.W., 2008, Platinum-group element abundances and Os isotopic composition of mantle peridotites from the Mamonia complex, Cyprus: Chemical Geology, v. 252, p. 78–90, doi: 10.1016/j.chemgeo.2007.09.002.

Büchl, A., Brügmann, G., Batanova, V.G., Münker, C., and Hofmann, A.W., 2002, Melt percolation: The evolution of Os isotope heterogeneities in the mantle sequence of the Troodos ophiolite, Cyprus: Geochimica et Cosmochimica Acta, v. 66, p. 3269–3282, doi: 10.1016/S0016-7037(01)00947-3.

Dale, C.W., Gannoun, A., Burton, K.W., Argles, T.W., and Parkinson, I.J., 2007, Rhenium-osmium isotopic constraints on the Cuobuzha peridotite: Journal of Petrology, v. 48, p. 1973–1993, doi: 10.1093/petroj/48.11.1973.

Lee, C.T.A., Brandon, A.D., and Norman, M., 2003, Vanadium in peridotites as a proxy of Paleo-O2 during partial melting, prospects, limitations and implications: Geochimica et Cosmochimica Acta, v. 67, p. 587–608, doi: 10.1016/S0016-7037(02)01299-5.

Liu, J., Xu Jifeng, Suzuki, K., He Bin, Xu Yigang, and Ren Zhongyuan, 2010, Os, Nd and Sr isotope and trace element geochemistry of the Mulu picrites: Insights into the mantle source of the Emeshan large igneous province: Lithos, v. 119, p. 108–122, doi: 10.1016/j.lithos.2010.04.004.

Liu Dongyang, Yang Jingziu, Xiong Fahui, Liu Fei, Wang Yunpeng, Zhou Wenda, and Zhao Yijue, 2014, Composition characteristics and tectonic setting of the Dajiweng peridotite in the western Yarlung-Zangbo ophiolite belt: Acta Petrolea Sinica, v. 30, p. 2164–2184.

Pearce, J.A., Barker, P.F., Edwards, S.J., Parkinson, I.J., and Leat, P.T., 2000, Geochemistry and tectonic significance of peridotites from the South Sandwich arc-basin system, South Atlantic: Contributions to Mineralogy and Petrology, v. 139, p. 263–356, doi: 10.1007/s004100505672.

Pearce, J.A., Barker, P.F., Edwards, S.J., Parkinson, I.J., and Leat, P.T., 2000, Geochemistry and tectonic significance of peridotites from the South Sandwich arc-basin system, South Atlantic: Contributions to Mineralogy and Petrology, v. 139, p. 263–356, doi: 10.1007/s004100505672.
Saccani, E., Dilek, Y., Marroni, M., and Pandolfi, L., 2015, Continental margin ophiolites of neotethys: Remnants of ancient Ocean–Continent Transition Zone (OCTZ) lithosphere and their geochemistry, mantle sources and melt evolution patterns: Episodes, v. 38, p. 230–249, doi:10.1884/epis/2015/v38i4/82418.

Saccani, E., Dilek, Y., and Photiades, A., 2017, Time-Progressive mantle—melting evolution and magma production in a Tethyan marginal sea: A Case study of the Albanide-Hellenide ophiolites: Lithosphere, doi:10.1130/L602.1.

Saka, S., Uysal I., Akmaç, M.R., Khalilwoda, M., and Hochleitner, R., 2014, The effects of partial melting, melt-mantle interaction and fractionation on ophiolite generation: Constraints from the Late Cretaceous Pozzanti-Karsanti ophiolite, southern Turkey: Lithos, v. 202–203, p. 300–318, doi:10.1016/j.lithos.2014.05.027.

Salters, V.J.M., and Stracke, A., 2004, Composition of the depleted mantle: Geochemistry, Geophysics, Geosystems, v. 5, Q05B07, doi:10.1029/2003GC000597.

Shallo, M., and Dilek, Y., 2003, Development of the ideas on the origin of Albanian ophiolites, in Dilek, Y., and Newcomb, S., eds., Ophiolite concept and the evolution of geological thought: Geological Society of America Special Paper 373, p. 351–364, doi:10.1130/0-8137-2373-6.351.

Sharma, M., and Wasserburg, G.J., 1996, The neodymium isotopic compositions and rare earth patterns in highly depleted ultramafic rocks: Geochimica et Cosmochimica Acta, v. 60, p. 4537–4550, doi:10.1016/S0016-7037(96)00280-3.

Shirey, S.B., and Walker, R.J., 1998, The Re-Os isotope system in cosmochemistry and high-temperature geochemistry: Annual Review of Earth and Planetary Sciences, v. 26, p. 423–500, doi:10.1146/annurev.earth.26.1.423.

Smoliar, M.I., Walker, R.J., and Morgan, J.W., 1996, Re-Os ages of group IIA, IIIA, IVA, and IVB iron meteorites: Science, v. 271, p. 1099–1102, doi:10.1126/science.271.5252.1099.

Uysal, I., Yalçın, E.E., Karşı, O., Dilek, Y., Burhan, S.M., Olt İ, C.J., Tiepolo, M., and Meisel, T., 2012, Coexistence of abyssal and ultra-depleted SSZ type mantle peridotites in a Neo-Tethyan ophiolite in SW Turkey: Constraints from mineral composition, whole rock geochemistry (major-trace-REE-PGE), and Re-Os isotope systematic: Lithos, v. 132–133, p. 230–249, doi:10.1016/j.lithos.2014.05.027.

Zhou Meifu, Robinson, P.T., Malpas, J., Edwards, S.J., and Qi Liang, 2005, REE and PGE geochemistry of the Skenderbeu Massif, Mirdita Ophiolite, Albania: Lithosphere, doi:10.1130/L606.1.

Yang Jingsui, Meng Fancong, Xu Xiangzhen, Robinson, P.T., Dilek, Y., Makeyev, A.B., Wirth, R., Wiedenbeck, M., and Cliff, J., 2015, Diamonds, native elements and metal alloys from chromites of the Ray-Iz ophiolite of the Polar Urals: Gondwana Research, v. 27, p. 507–524, doi:10.1016/j.gr.2014.08.001.

Zheng Lei, Zhi Xiachen, and Reisberg, L., 2008, Re-Os systematics of the Raobazhai peridotite massifs from the Dabie orogenic zone, eastern China: Chemical Geology, v. 268, p. 1–14, doi:10.1016/j.chemgeo.2009.06.021.

Zhou Wenda, Yang JingSui; Zhao JunHong, Xiong FaHui, Ma ChangQian, Xu XiangZhen, Li FengHua, and Liu Fei, 2014, Mineralogical study and the origin discussion of Purang ophiolite peridotites, western part of Yarlung-Zangbo Suture Zone (YZSZ), southern Tibet: Acta Petrolei Sinica, v. 30, p. 2188–2203.

Wu, W.W., Yang, J.S., Dilek, Y., Milushi, I., and Lan, D.Y., 2017, Multiple Episodes of melting, depletion and refertilization of the Tethyan Mantle: Petrogenesis of the peridotites and chromitones in the Jurassic skenderbeu Massif, Mirdita Ophiolite, Albania: Lithosphere, doi:10.1130/L606.1.

Xiong, F., Yang, J., Liang, F., Ba, D., Zhang, J., Xu, X., Li, Y., and Zhao, Liu, 2011, Zircon U-Pb ages of the Dongbo ophiolite in the western Yarlung Zangbo suture zone and their geological significance: Acta Petrolei Sinica, v. 27, p. 3223–3238 (in Chinese with English abstract).

Xu Zhiqin, Dilek, Y., Yang Jingsui, Liang Fenghua, Liu Fei, Ba Dengzhu, Cai Zhihua, Li Wenguang, Dong Hanwen, and Ji Shaocheng, 2015, Crust structure of the Indus-Tsangpo suture zone and its ophiolites in southern Tibet: Gondwana Research, v. 27, p. 507–524, doi:10.1016/j.gr.2014.08.001.

Yang Jingsui, Robinson, P.T., and Dilek, Y., 2014, Diamonds in ophiolites: A little-known diamond occurrence: Elements, v. 10, p. 129–126, doi:10.2113/elements.10.2.123.

Yang Jingsui, Meng Fancong, Xu Xiangzhen, Robinson, P.T., Dilek, Y., Makeyev, A.B., Wirth, R., Wiedenbeck, M., and Cliff, J., 2015, Diamonds, native elements and metal alloys from chromites of the Ray-Iz ophiolite of the Polar Urals: Gondwana Research, v. 27, p. 459–486, doi:10.1016/j.gr.2014.07.004.

Zheng Lei, Zhi Xiachen, and Reisberg, L., 2008, Re-Os systematics of the Raobazhai peridotite massifs from the Dabie orogenic zone, eastern China: Chemical Geology, v. 268, p. 1–14, doi:10.1016/j.chemgeo.2009.06.021.