**An Andean-type arc system in Rodinia constrained by the
Neoproterozoic Shimian ophiolite in South China**

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ABSTRACT

The configuration of the supercontinent Rodinia has long been a matter of debate; the key controversy is the position of South China in Rodinia. We report an incomplete Neoproterozoic ophiolite sequence, including gabbros and serpentinitized peridotites intruded by mafic dikes, near Shimian (Sichuan Province), along the western margin of the Yangtze Block in South China. Serpentinitized peridotites have very low REE (0.14-1.16 ppm) and trace element concentrations, and are interpreted as parts of a depleted mantle sequence. Chromites from the serpentinitized peridotites have low TiO_2 (< 0.3 wt.%) and Fe_2O_3 (<7.6 wt.%), and moderate $\text{Cr}/(\text{Cr}+\text{Al})$ (0.48-0.67) and $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ (0.42-0.67) ratios and are clearly indicative of strong depletion of the host peridotites, similar to those of supra-subduction zone (SSZ). Mafic dikes and gabbros contain zircon grains with similar U-Pb ages of ~800 Ma, and are chemically akin to MORB-like tholeiitic basalts and boninite-series volcanic rocks reported in other SSZ ophiolites and in the Izu-Bonin-Mariana arc system. Therefore, the serpentinitized peridotite, mafic dikes and gabbros together appear to form a SSZ-type ophiolite assemblage preserving the accretion of oceanic lithosphere to the western Yangtze Block. The age and location of the Shimian ophiolite rule out the possibility that South China was located in the centre of Rodinia. Instead, the Neoproterozoic arc-affinity igneous rocks at the western margin of the Yangtze Block are well correlated with those in Greater India and Madagascar. These three blocks thus together formed a giant Andean-type arc system along the NW margin of Rodinia that existed for more than 100 Mys.

Keywords: Ophiolite, Andean-type arc system, Neoproterozoic, South China, Rodinia

1. Introduction

The supercontinent Rodinia is supposed to have been assembled and then broken up during late Mesoproterozoic to Neoproterozoic time (Dalziel, 1991; Hoffman, 1991; Moores, 1991; Li et al., 1995, 2008; Zheng, 2004). Inadequate paleomagnetic data, widespread Grenville-age orogenic belts and discontinuous basement provinces have resulted in uncertainties in paleogeographic reconstructions and contentious interpretations (Goodge et al., 2008). In the past few decades, many reconstruction models have been proposed for Rodinia's pre-breakup paleogeography (e.g. Li et al., 2008; Evans, 2009). Laurentia is flanked by more than 14000 km of late Precambrian rift margins and thus is commonly regarded as being at the centre of Rodinia (e.g. Hoffman, 1991; Li et al., 2008). The question remains what conjugate pieces rifted from Laurentia's margins; at the heart of the controversy is the position of South China in Rodinia (Evans et al., 2000; Cawood et al., 2013). Most reconstructions postulate that western U.S. (Laurentia) connected with Australia – East Antarctica, based on correlations of Neoproterozoic rift-margin stratigraphy and Mesoproterozoic Grenville-age fold belts (Dalziel, 1991; Hoffman, 1991; Moores, 1991; Ross et al., 1992; Goodge et al., 2008). Li et al. (1995, 2008) proposed an alternative model that places South China between Australia and Laurentia in Rodinia, serving as the “missing link” between these two continents. According to the “Missing-Link” model, the late-

Mesoproterozoic to early Neoproterozoic strata (>850 Ma) along the southeastern margin of the Yangtze Block in South China were part of Grenville orogen fold belts, whereas the middle to later Neoproterozoic strata and igneous rocks (<850 Ma) resulted from upwelling mantle plume activities during the breakup of Rodinia (Li et al., 1995, 2007, 2008, 2009). However, the widespread Neoproterozoic arc-like igneous rocks at the western margin of the Yangtze Block and the SSZ-type ophiolite identified in this study suggest that the early proposed construction models should be further evaluated.

Supra-subduction zone (SSZ) ophiolites are generally considered to represent oceanic lithosphere formed in the extensional upper plates of subduction zones and then tectonically emplaced onto continental margins (Stern et al., 2012). Their sequences of igneous rocks vary from MORB-like tholeiitic to boninite-series rocks similar to those of the Izu-Bonin-Mariana subduction system. The sequences preserve evidence of the tectonic and magmatic evolution at convergent margins in the early stages of arc formation (Kusky, 2004; Dilek et al., 2008; Kusky et al., 2011; Dilek and Furnes, 2011; Whattam and Stern, 2011). Therefore, recognition of an SSZ-type ophiolite in the geologic record can offer crucial evidence of tectonic setting and a key constraint on continental reconstruction. Unfortunately, such ophiolites tend to be dismembered and eroded and thus are rarely preserved within ancient continental blocks.

In this paper, we report an incomplete ophiolitic sequence in Shimian of the western margin of the Yangtze Block in South China. Both gabbros and basaltic dikes in this sequence contain zircon grains with U-Pb ages of ~800 Ma. New

whole rock and chromite mineral chemical compositions are used to demonstrate that the Shimian mafic-ultramafic body is in fact an SSZ-type ophiolite and address a key piece in the Rodinia puzzle. The presence of an SSZ-type ophiolite in this location at 800-Ma leads us to reconsider previously popular Rodinia reconstruction models. Combined with the previously published results, our conclusion is that South China was probably not centrally located in Rodinia but rather formed part of a giant Andean-type arc system along the northwestern margin of Rodinia during the Neoproterozoic.

2. Geological background

South China consists of the Yangtze Block and the Cathaysia Block (Fig. 1). The Yangtze Block is separated from the North China Craton to the north by the Triassic Qinling-Dabie orogenic belt (QDOB), and is bounded by the Tibetan Plateau to the west.

2.1. Regional geology

The Jiangnan Fold Belt (also known as the Jiangnan Orogen or Sibao Orogen) has long been considered as a collisional zone along which the Yangtze Block and the Cathaysia Block were amalgamated together to form the South China continent (Fig. 1), although the timing of the collision is still controversial. The Neoproterozoic igneous and sedimentary rocks in the southeastern Yangtze Block consist mainly of three ages of rocks which show different lithology and geochemical features (Fig. 1). The ca. 0.9-1.0 Ga rocks comprise limited arc-affinity volcanic rocks, granites and ultramafic complexes, as well as minor mica schists (Shu and Charvet, 1996; Li et al., 2007; Shu et al., 2011). The middle

Neoproterozoic strata (ca. 850-830 Ma), such as the Sibao Group and its equivalents, were strongly deformed and intruded by numerous ca. 820 Ma granitoid plutons. The unconformably overlying late Neoproterozoic strata (Banxi Group and its equivalents) were deposited in the Nanhua basin in the intracontinental extensional setting during ~820 to ~725 Ma (Wang and Li, 2003). Li et al. (2007, 2009) suggested that the Jiangnan Fold Belt was part of Grenville orogenic fold belts, and the ca. 0.9-1.0 Ga igneous and metamorphic rocks were generated during the collision between the Yangtze and Cathaysia Blocks, whereas the middle- to late Neoproterozoic sedimentary rocks (<850 Ma) were formed in a rift setting due to upwelling mantle plume activities during the breakup of Rodinia. However, other scientists argued that the Jiangnan Fold Belt was not a Grenville-age orogenic belt; the deformation of the middle Neoproterozoic strata and the unconformity between the middle- (e.g. the Sibao Group) and late Neoproterozoic strata (e.g. the Banxi Group) mark the final collision between the Yangtze and Cathaysia Blocks; the intracontinental rift did not occur until opening of the Nanhua Basin at ~820 Ma (Fig. 1; Zheng et al., 2007, 2013; Zhao et al., 2011; Wang et al., 2013b; Zhao, 2015).

In the northern Yangtze Block (Fig. 1), the South Qinling Belt mainly consists of middle to late Neoproterozoic igneous-sedimentary rocks that were intruded by numerous ca. 650 Ma mafic-ultramafic intrusions (Bader et al., 2013; Wang et al., 2013a). The rocks in the Qinling-Dabie orogenic belt underwent extensive HP/UHP metamorphism during the Triassic continental collision between the North China and the South China Blocks (Zheng et al., 2006, 2011,

and references therein; Bader et al., 2013). In the Kongling region, the 855-826 Ma tonalite-trondhjemite-granite series plutons show arc-affinity geochemical features (Zhao et al., 2013; Gao et al., 2016). A mafic-ultramafic body in the same region was recently identified as an ophiolite mélangé, with zircon U-Pb ages of 1100-985 Ma (Peng et al., 2012).

Along the western margin of the Yangtze Block from the Hannan region to the north and the Panzhihua region to the south (Fig. 1), ca. 1000-Ma strata are sparsely distributed; the alkaline volcanic rocks of this age are thought to have formed in a rift-related tectonic setting (Geng et al., 2007; Chen et al., 2014). However, the Neoproterozoic igneous rocks in the region are characterized by voluminous arc-affinity felsic intrusions and minor mafic-ultramafic bodies with ages ranging from 860 to 750 Ma (Fig. 1). Penecontemporaneous volcano-sedimentary basins are discontinuously distributed in the area, as indicated by the Suxiong Formation, and the Bikou and Yanbian Groups (Li et al., 2002; Zhou et al., 2006a; Dong and Santosh, 2016). The western margin of the Yangtze Block underwent extensive and strong deformation associated with the Mesozoic convergence among the Qiangtang, North and South China Blocks and the Cenozoic collision between the Indian and the Eurasian plates, resulted in series of brittle faults and semi-brittle folds which are the dominant tectonic features in the region (Fig. 1; Zhou et al., 2008; Roger et al., 2010; Yan et al., 2011).

2.2. The Shimian ophiolite

The Shimian ophiolite is located on the western margin of the Yangtze Block (Figs. 1 and 2). The county of Shimian, whose name literally translates to

“asbestos”, is named after the asbestos mine associated with the serpentinized peridotite of the Shimian ophiolite (Shen et al., 2002). The regional scale sinistral NW-SE-trending Nanyahe fault crosscuts the Shimian ophiolite with about 8 km of displacement, separating it into the north and south parts (Fig. 2A). The ophiolite is intruded by ca. 790 Ma granite to the north (Figs. 2B and 3A), and is unconformably overlain by the ca. 803 ± 12 Ma volcano-sedimentary rocks of the Suxiong Formation to the south (Fig. 2B; Zeng et al., 1982; Li et al., 2002). Ophiolitic clasts have been identified in the Suxiong Formation (Zeng et al., 1982; Shen et al., 2002). To the east and west, the lens of ophiolite was truncated by a series of little faults (Fig. 2B). The ophiolite is composed of a gabbro unit approximately 300-500 m thick and a serpentinized peridotite unit about 1 km thick (Fig. 2B). In the peridotite unit, there are numerous mafic dikes with width ranging from 0.5 to few meters (Fig. 3B). Basalts and sedimentary rocks were reported in the previous studies, but are rare (Zeng et al., 1982), most of which were probably dismembered and eroded during the subsequent tectonic events.

Based on our detailed field investigation, overall two major phases of structures can be identified in this region. The early phase of structure occurred under a NW-SE shortening tectonic regime and was characterized by the semi-brittle fabrics that are mostly preserved in the ophiolite unit (Fig. 3C). The serpentinized peridotite unit has been extensively deformed and sheared into different boudins by a series of small-scale ductile / semi-brittle shear zones (Fig. 3D), indicating a top-to-SE sense of thrust. In our interpretation, these early structures most likely record a subduction of an ancient oceanic lithosphere that

183 resulted in the overthrust of the ophiolite. By contrast, the late phase of structure
184 was mostly developed under a NE-SW shortening tectonic regime and is
185 characterized by a series of top-to-SW thrust/reverse faults that are pervasively
186 preserved in all of the lithological units (Figs. 3E and F). In some places, the
187 original intrusive contact between the granite and the gabbro has been reworked
188 to be a tectonic contact (Fig. 3E). These small scale faults, together with the
189 large scale strike-slip faults (Fig. 2A) are most likely related to the Cenozoic
190 shortening and uplift event along the Longmenshan area (Wang and Burchfiel,
191 2000; Zhou et al., 2008).

192 Rocks from the gabbro unit are coarse- to fine-grained and consist mainly of
193 plagioclase, hornblende and clinopyroxene with minor Ti-Fe oxide (Figs. 4A and
194 B). Clinopyroxene are partially altered into serpentine and chlorite (Fig. 4B). The
195 dikes are composed of diabase that consists of clinopyroxene and plagioclase
196 associated with minor hornblende and Ti-Fe oxide (Fig. 4C and D). The
197 ultramafic rocks have been totally altered into serpentine and generally preserve
198 chromite minerals rimmed by magnetites.

200 **3. Analytical methods**

201 **3.1. SHRIMP zircon U-Pb dating**

202 Zircon grains were carefully separated using conventional heavy liquid and
203 magnetic techniques. They were mounted in epoxy and polished. The mounts
204 were coated with gold and then took cathodoluminescence (CL) images to reveal
205 zircon internal structures for analyses. Zircon U-Pb dating were carried out at the

Chinese Academy of Geological Sciences, Beijing, China. Analytical procedures using the SHRIMP II are described in Wan et al. (2005). Elemental abundances and $^{206}\text{Pb}/^{238}\text{U}$ ratios were calibrated by SL13 and TEM standards, respectively (Wan et al. 2005 and references therein). Common Pb was corrected using measured ^{204}Pb abundances.

3.2. Zircon Hf isotope analyses

Zircon Hf isotopes were analyzed at the State Key Laboratory of Geological Processes and Mineral Resources (GPMP), China University of Geosciences (CUG), Wuhan. Detailed analytical conditions and procedures are described in Hu et al. (2012). The experiments used the combination system of a Neptune Plus MC-ICP-MS and a Geolas 2005 excimer ArF laser ablation system with a laser spot size of 44 μm . Each measurement comprises two steps, including 20 second background-signal acquisition and 50 second sample-signal acquisition. Off-line analyte signal selection and integration, as well as mass bias calibrations were carried out using the soft ICPMSDataCal (Liu et al., 2010).

3.3. Major and trace element analyses

Major element analyses were also carried out at GPMR, CUG, Wuhan. The powder samples were firstly fused to produce glass beads, and then analyzed by the X-ray fluorescence (XRF) method using a Shimadzu Sequential 1800 spectrometer with accuracies better than 2%. Trace elements were analyzed at Institute of Geochemistry, Chinese Academy of Sciences (CAS). The analytical procedures are described in detail by Qi et al. (2000). The samples were digested by $\text{HF}+\text{HNO}_3$ in closed beakers in high-pressure stainless steel bombs.

Two standard samples (BHVO-1 and SY-4) were used as reference materials, and pure elemental standards as external calibration in the experiments. The sample solutions were analyzed using an ELAN DRC-e ICP-MS with accuracies better than 5-10 %.

3.4. Electron probe micro-analyses

Chemical analyses of chromite were carried out using a JXA-8200 electron probe at the GPS Division Analytical Facility of Caltech. The quantitative analyses were performed using an accelerating voltage of 15 kV and a specimen current of 25 nA with in focused mode. A precision approaching 0.5% relative and accuracy as good as 1-2% can be obtained.

4. Results

4.1. Zircon U-Pb ages of the Shimian ophiolite

Three samples from the gabbro unit were used for zircon U-Pb dating. Samples SM137 and SM140 contain a large number of euhedral to subhedral equant zircon grains. Some are fragmented grains that contain altered fractures and holes (Fig. 6). A few zircons show thin overgrowths, indicating subsequent post-magmatic stress and recrystallization. Very subtle metamorphic recrystallization may result in extensive Pb loss (Connelly, 2001). Zircon grains from the two samples show large range of U and Th concentrations (Table 1, Fig. 5). High-U (and Th) grains from sample SM137 generally give discordant young ages of 260 Ma to 773 Ma that suggest partial to complete resetting by younger post-crystallization events. The eight low-U grains from SM137 give reasonably concordant $^{206}\text{Pb}/^{238}\text{U}$ ages ranging from 741 Ma to 847 Ma with a weighted

mean age of 792 ± 32 Ma (MSWD=12, Fig. 6). Similarly, five high-U analyses from sample SM140 yield young ages of 242-281 Ma (Table 1, Fig. 5), whereas nine low-U grains give nearly concordant $^{206}\text{Pb}/^{238}\text{U}$ ages of 767-826 Ma with a weighted mean age of 796 ± 15 Ma (MSWD=0.93, Fig. 6). Sample SM48 also contains two groups of zircon grains. Seven grains show bright CL images and old concordant $^{206}\text{Pb}/^{238}\text{U}$ ages (1004 to 1046 Ma; Table 1); the weighted mean age is 1026 ± 16 Ma ($n=7$, MSWD=2.3). Nineteen zircons preserve magmatic oscillatory zoning and give concordant $^{206}\text{Pb}/^{238}\text{U}$ ages ranging from 769 to 872 Ma with a weighted mean age of 806 ± 11 Ma (MSWD=9.9; Fig. 6). Therefore, despite some resetting, we recognize that the three samples give consistent U-Pb ages of ca. 800 Ma that likely represent the formation age of the gabbro unit. The young ages may represent a metamorphic event at 260 Ma, coinciding temporally with the mantle plume that produced the voluminous Emeishan flood basalts in the region (Zhou et al., 2002, 2008 and references therein). The older age (mean age = 1026 ± 16 Ma) is similar to the age of the Miaowan ophiolite in the northern margin of the Yangtze Block (1100-985 Ma, Peng et al., 2012), suggesting that these zircon grains were probably inherited from the early formed oceanic crust.

Sample SM18 from a mafic dike intruding the serpentinized peridotite contains large subhedral to anhedral zircon grains, 50-150 μm in length. Most grains preserve oscillatory zoning, indicating a magmatic origin (Fig. 6). Two analyses yielded young or discordant ages (Table 1). The remaining 18 analyses yield two groups of $^{206}\text{Pb}/^{238}\text{U}$ ages ranging from 807 ± 11 Ma to $860 \pm$

12 Ma and from 766 ± 11 Ma to 779 ± 12 Ma with weighted mean ages of 830 ± 7 Ma and 774 ± 9 Ma, respectively (Fig. 6). It should be noted that the two group zircons show similar magmatic textures, and therefore the age differences are supposed to have resulted from limited grains and analysis errors. If all the data are put together, they will give an average age of 811 ± 15 Ma ($n=18$, MSWD=6.7) that probably represents the emplacement time. Within mutual uncertainty, the mafic dikes have similar U-Pb ages to the gabbro unit. Therefore, the formation age of the Shimian ophiolite is considered to be ~ 800 Ma.

4.2. Zircon Hf isotopes

Two samples (SM48 from the gabbro unit and SM18 from the dike) were used for zircon Lu-Hf isotope analyses. ϵ_{Hf} values were calculated using the Lu-Hf isotopic data and the age of zircon (Table 2). Only hafnium isotope compositions for zircons with concordant ages are discussed in this study.

Sample SM48 contains two groups of zircon grains which show different Hf isotope compositions (Table 2). The ca. 800 Ma magmatic zircons have $^{176}\text{Lu}/^{177}\text{Hf}$ ratios ranging from 0.000534 to 0.001722 and present-day $^{176}\text{Hf}/^{177}\text{Hf}$ ratios from 0.282230 to 0.282344, giving ϵ_{Hf} from -2.23 to +2.81 with an average value of -1.30 ± 0.22 . The ca. 1.0 Ga inherited grains show similar $^{176}\text{Lu}/^{177}\text{Hf}$ ratios (0.000335 to 0.001941), but relatively constant and high present-day $^{176}\text{Hf}/^{177}\text{Hf}$ ratios (0.282480 to 0.282527), yielding strong positive ϵ_{Hf} values ranging from +12.21 to +13.57 with an average value of 12.37 ± 0.40 (Table 2).

Eighteen magmatic zircons from sample SM18 show $^{176}\text{Lu}/^{177}\text{Hf}$ and present-day $^{176}\text{Hf}/^{177}\text{Hf}$ ratios ranging from 0.000436 to 0.003726 and from

0.282323 to 0.282627, respectively. They display a large range of ϵ_{Hf} values continuously varying from +10.92 to +1.87 (Table 2).

4.3. Whole rock and mineral chemistry

The serpentized peridotites have high MgO (36.94-40.25 wt.%), low SiO₂ (37.65-41.95 wt.%) and CaO (0.04-0.77 wt.%) (Table 3, Fig. 7). They have very low trace element concentrations with REE ranging from 0.14 to 1.16 ppm (Fig. 8). Rocks from the gabbro unit and the dikes have major element concentrations that are similar (Fig. 7). Their SiO₂ contents range from 37.31 to 51.18 wt.% while CaO varies from 8.21 to 24.88 wt.%; these oxides are negatively correlated. They have highly variable MgO (4.95-11.18 wt.%), Al₂O₃ (10.84-16.16 wt.%), Fe₂O₃ (7.6-11.8 wt.%) and TiO₂ (0.33-1.99 wt.%) but in all major element plots the gabbros and dikes form a single coherent array. However, they show different trace element signatures (Table 3): rocks from the gabbro unit show more LREE-depleted REE patterns and lower trace element concentrations than those from the mafic dikes (Fig. 8).

Chromites in the serpentized peridotite are anhedral to subhedral, and are enclosed within serpentites (Fig. 9). Most grains are partially replaced by magnetite that forms thin rims around or micron-scale veinlets within the grains (Fig. 9). The internal fresh chromites have low TiO₂ (<0.3 wt.%) and Fe₂O₃ (<7.6 wt.%), and high Cr₂O₃ (37.91-51.13 wt.%) and Al₂O₃ (17.07-29.75 wt.%). Their 4-oxygen formulas thus have low Fe³⁺ (<0.18), high Al (0.65 to 1.07) and especially high Cr (0.91 to 1.31) cations (Table 4).

5. Discussion

5.1. SSZ-type Shimian ophiolite

The calculated CIPW modal mineralogy of the peridotites range from 51-81% olivine, 17-45% orthopyroxene, <2% clinopyroxene, and <2% anorthitic plagioclase. Whole rock compositions of the peridotites have negligible Al_2O_3 , CaO, TiO_2 and Na_2O , very low REE and incompatible trace element concentrations (Table 3, Figs. 7-8), indicating a highly depleted residual mantle source. Although chromite grains in the serpentinized peridotite are partially replaced by magnetite (Fig. 9), the internal fresh chromites have chemical compositions significantly different from those of chromites in Alaskan-type mafic-ultramafic complexes or arc volcanic rocks; both are rich in Ti and Fe and depleted in Al (Himmelberg and Loney, 1995; Figs. 10A-D), suggesting that the Shimian peridotite is not a section of an arc root. The chromites are also different from those of komatiites and continental flood basalts, as well as stratiform complexes (Figs. 10C-D; Wang et al., 2005). However, they are plotted within the overlap region of SSZ- and MORB-affinity peridotites in the plot of TiO_2 vs. Al_2O_3 (Fig. 10A). Their $\text{Cr}/(\text{Cr}+\text{Al})$ and $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ ratios are well within the field associated with supra-subduction zone (SSZ) ophiolites and at the very limit of highly depleted abyssal peridotites (Fig. 10B), suggesting that the Shimian peridotite was more likely formed in a subduction-related oceanic extensional environment. Thus, both whole rock and mineral chemistry indicate that the Shimian peridotite represents part of an SSZ-type ophiolite.

The dikes and gabbro unit in this study further demonstrate that they are

344 part of an SSZ-type ophiolite. MORB-like tholeiitic basalts and boninite series
345 rocks are widespread within SSZ ophiolites and in some primitive arc settings
346 (Stern and Bloomer, 1992; Stern, 2004; Dilek et al., 2008; Cooper et al., 2010;
347 König et al., 2010; Reagan et al., 2010; Stern et al., 2012; Parlak, 2016). The
348 magmatic rock sequences preserved in most Tethyan ophiolites vary from
349 MORB-like to upward boninitic assemblages that are lithologically and
350 geochemically similar to those of the Izu-Bonin-Mariana forearc, recording
351 progressive enrichment of the mantle source by slab-derived materials in the
352 early stages of the subduction system (Reagan et al., 2010; Dilek and Furnes,
353 2011; Whattam and Stern, 2011). Although the whole-rock composition of the
354 mafic dikes and gabbro unit at Shimian are similar in general, there are
355 differences in their trace element compositions that are consistent with cumulate
356 versus mostly liquid origins (Figs. 7 and 8). Light Rare Earth Elements (LREE) in
357 mafic dikes are negatively correlated with SiO_2 and Al_2O_3 , and positively with
358 MgO and CaO (Table 3), suggesting that primary magmas of the dikes may have
359 been derived from a LREE-depleted mantle source and LREE-enrichment in
360 some samples resulted from magma differentiation (Fig. 8). Both the evolved and
361 primitive mafic dikes show slightly more LREE-enriched REE patterns (Fig. 8),
362 and have higher Ti/Sc , Ti/V , Sm/Yb and La/Sm ratios than the rocks from the
363 gabbro unit (Fig. 11). The mafic dikes have MORB-like geochemical features,
364 whereas the gabbros have affinity to boninitic igneous rocks. The temporally
365 associated mafic dikes and gabbro unit thus resemble the closely associated
366 MORB-affinity tholeiitic basalts and boninite-series volcanic rocks in the Izu-

Bonin-Mariana subduction system and within many SSZ ophiolites, respectively (e.g. Dilek et al., 2008; Whattam and Stern, 2011).

MORB-like tholeiitic basalts are generally derived from a depleted mantle source, whereas boninites are thought to be partial melts of the residual refractory mantle refertilized by slab-derived fluids (Reagan et al., 2010; Whattam and Stern, 2011). Melts from subducted sediments are also suggested to contribute to boninite source mantle in the Ordovician Betts Cove ophiolite (Bédard, 1999), the Cretaceous Troodos ophiolite (König et al., 2010) and Oman ophiolite (Haase et al., 2015). Zircon ϵ_{Hf} values in this study reflect the generation of the ophiolite above a subducting slab. The ca. 1.0 Ga inherited zircon grains show very high ϵ_{Hf} values (+12.21 to +13.57), suggesting a MORB-like depleted mantle source. The 800-Ma magmatic zircons show lower and more variable ϵ_{Hf} values; the mafic dikes display a large range of ϵ_{Hf} values (+10.92 to +1.87), whereas the gabbros show low and constant ϵ_{Hf} values (-2.23 to +2.81), recording an increasing input of a subduction component with time. This proposed scenario is consistent with their zircon U-Pb ages and field relationships (Figs. 3B and 6), which show that the mafic dikes are likely to be slightly older than the gabbro unit. Therefore, the serpentinized peridotite, MORB-like mafic dikes and boninite-affinity gabbro unit together are interpreted as an SSZ-type ophiolite mélange formed during the accretion of oceanic lithosphere to the western Yangtze Block.

5.2. Marginal position of South China in Rodinia

Previous studies generally considered that Rodinia was assembled between

1300 and 900 Ma and broke up from 750 Ma (Li et al., 2007, 2008, 2009 and references therein). The “Missing-Link” model suggests that South China was located at the centre of the supercontinent Rodinia, that the Jiangnan Fold Belt was formed during the Grenville orogeny, and that the Neoproterozoic igneous rocks around the Yangtze Block resulted from breakup of Rodinia due to upwelling of a mantle plume (Fig. 1; Li et al., 1995, 2008). However, this model was challenged by the recently identified evidence. New zircon U-Pb dating reveals that the Jiangnan Fold Belt formed at around 830 Ma (Zhao et al., 2011), arguing against its correlation with the ca. 1000-Ma orogenic belts in Australia – East Antarctica and western Laurentia. The Neoproterozoic granitoids, mafic and ultramafic rocks along the western margin of the Yangtze Block show arc-affinity geochemical characters that are inconsistent with their formation in rift settings (Zhou et al., 2002; Zhao et al., 2011; Dong and Santosh, 2016). In addition, the early phase of structures preserved in the Shimian ophiolite also indicate a nearly NW-SE-oriented shortening, which might have been resulted from the active subduction of an ancient oceanic lithosphere along the western margin of the Yangtze Block (Fig. 3E, F).

Peng et al. (2012) reported 1100-985 Ma SSZ-type ophiolite on the northern margin of the Yangtze Block that was emplaced before 850 Ma. The Shimian SSZ-type ophiolite identified in this study further indicates that oceanic slab subduction was still on-going at around 800 Ma beneath the western margin of the Yangtze Block. This interpreted setting is entirely different from the ca. 825-800 Ma Gairdner-Amata dike swarms in Australia that are thought to have been

derived from the mantle plume during initial breakup of Rodinia (Wingate et al., 1998). The SSZ-type ophiolite identified in this study shows that the margins of the Yangtze Block are not correlative with southern Australia and western Laurentia, and suggest that South China was unlikely to have been the central part of Rodinia during the Neoproterozoic. Therefore, it was most likely located (probably the only option consistent with all the evidence) along the margin of Rodinia during the Neoproterozoic.

5.3. Andean type arc-system of Rodinia

The available limited Paleomagnetic data for South China for the Neoproterozoic time permit several reconstruction models (Evans et al., 2000). In one reconstruction model, paleomagnetic data from the 820-800 Ma mafic dykes in the Yanbian Basin of the western Yangtze Block provided a possible position of South China that was adjacent to western Australia and southern India in Rodinia (Niu et al., 2016). Paleomagnetic data from the middle Cambrian sediments of the western Yangtze Block also reveal that South China was connected with the northwestern margin of the Australian Block from 750-380 Ma (Yang et al., 2004). These two regions also show similar Cambrian faunal provinces (Burrett et al., 1990). The reconstructed position of South China within Rodinia is therefore most likely to the northwest of the Australian Block (Fig. 12).

India, Madagascar and the Seychelles islands are suggested to have been amalgamated along the margins of North Gondwana during the Neoproterozoic (Fig. 12; Ashwal et al., 2002; Jiang et al., 2003; Li et al., 2008; Yu et al., 2008; Cawood et al., 2013). The late Neoproterozoic rocks in the Yangtze Block of

South China and the Lesser Himalaya of northwestern India have similar rifting facies assemblages and carbonate platform architecture, with distinctive karstic unconformities at comparable stratigraphic levels (Jiang et al., 2003; Yin et al., 2010; Hofmann et al., 2011). In addition, U-Pb ages and Hf isotopes on detrital zircons from the late Neoproterozoic sediments in South China are very similar to those from Neoproterozoic to early Paleozoic strata in the Greater Himalaya, Lesser Himalaya, and North India (Yu et al., 2008 and references therein). Thus, it is possible that in the configuration of Rodinia, South China may have been adjacent to the Marwar Block in India, the Seychelles and Madagascar, all being located at northwest of Australia (Fig. 12). This paleoposition of South China is different from the previously suggested models in which South China was placed between western Laurentia and eastern Australia in Rodinia (Li et al., 1995, 2008).

In the western region of the Yangtze Block, there are Neoproterozoic mafic-ultramafic intrusions showing arc-affinity geochemical characteristics, suggesting a mantle source modified by subducted slab-derived fluids and melts (e.g. Zhou et al., 2006a; Zhao and Zhou, 2007). The widely distributed Neoproterozoic felsic rocks in the region are mainly composed of normal arc I-type and adakitic-type granitoids, thought to have been produced by melting of newly formed crust in an active continental margin (Zhou et al., 2002, 2006b). In addition, the contemporaneous arc sedimentary basins discontinuously found in the region are composed of flysch-type sedimentary sequences with intercalated arc pillow lavas (e.g. Yan et al., 2004; Zhou et al., 2006a). These igneous and sedimentary

assemblages define the >1000-km Panxi-Hannan arc system that lasted from 860 to 750 Ma along the western margin of the Yangtze Block (Fig. 1; Zhou et al., 2002; Zhao et al., 2011; Peng et al., 2012). These rock assemblages and geochemical compositions are very similar to those of Neoproterozoic igneous complexes in Northeastern Madagascar, the Seychelles island and Malani Igneous Suite in India that have ages ranging from 800 to 700 Ma and are thought to represent an active Andean-type margin above an eastward-dipping subduction zone on the western to northern margins of Rodinia (Tucker et al., 2001; Torsvik et al., 2001; Ashwal et al., 2002; Zhou et al., 2006a). Therefore, the arc systems from the above four blocks probably formed a long term and large active Andean-type margin at the northern edge of Rodinia during accumulation of the supercontinent (Cawood et al., 2016). The proposed model can easily explains similarities of geological and biological evolution among South China, India and Australia (e.g. Burrett et al., 1990; Jiang et al., 2003; Yang et al., 2004; Niu et al., 2016).

6. Conclusions

The 800-Ma Shimian SSZ-type ophiolite at the western margin of the Yangtze Block consists of gabbro and serpentinized peridotite that was intruded by mafic dikes. Chromites from the peridotite are chemically similar to those of supra-subduction zone (SSZ) peridotites, and the mafic dikes and gabbros are akin to MORB-affinity tholeiitic basalts and boninite-series volcanic rocks in the Izu-Bonin-Mariana arc system and other SSZ ophiolites, respectively. The age and location of the Shimian ophiolite suggest that South China was unlikely to

have been located in the centre of Rodinia, but was most likely to the northwest of the Australian Block and was correlated with Greater India and Madagascar. The arc affinity rocks from Madagascar, the Seychelles, Malani Igneous Suite in India and the western Yangtze Block together formed a giant Andean-type arc system along the northwestern margin of Rodinia during the Neoproterozoic.

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 780

FIGURE CAPTIONS

Figure 1. Simplified geological map showing distribution of Neoproterozoic igneous and sedimentary rocks in South China (modified from Zhao et al., 2011). TP = Tibetan plateau, QDOB = Qinling-Dabie orogenic belt. The Jiangnan Fold Belt is constrained by the deformed Mesoproterozoic to early Neoproterozoic strata (>830 Ma) and the Nanhua Basin by the later Neoproterozoic strata (<820 Ma). The Shimian ophiolite is located at western margin of the Yangtze Block (see details in Fig. 2).

Figure 2. Simplified geological map of the Shimian ophiolite, South China (modified from RGSR (1974) and RERMR (1966)).

Figure 3. Field photographs showing megascopic structures of the rocks. (A) An intrusive relationship between the Neoproterozoic granite and the gabbros; (B) mafic dikes intruded into the peridotite unit; (C) a series of early phase semi-brittle fabrics developed in the ultramafic rocks, indicating a top-to-SE sense of thrust; (D) a simplified sketch showing the early phase fabrics preserved in Fig. 3C; (E) A late phase tectonic contact between the granitic intrusion and the gabbro unit, indicating a top-to-SW sense of thrust; (F) Semi-brittle oblique foliations preserved in the granite, indicating a top-to-SW sense of thrust during the late phase of deformation.

Figure 4. Photomicrographs showing the mineral assemblages and textures of

the rocks from gabbro unit (A and B) and dikes (C and D). Pl=plagioclase,
Cpx=clinopyroxene, Hb=hornblende.

Figure 5. Plots of U and Th against $^{206}\text{Pb}/^{238}\text{U}$ age for zircons from the gabbro unit of the Shimian ophiolite.

Figure 6. Zircon U-Pb dating for gabbroic unit and mafic dikes of the Shimian ophiolite.

Figure 7. Major element plots for rocks from the Shimian ophiolite.

Figure 8. Chondrite-normalized REE patterns and primitive mantle-normalized spider diagrams for rocks from the Shimian ophiolite. The normalization values are from Sun and McDonough (1989).

Figure 9. Back-scattered electron (BSE) images of representative chromites from the serpentinized peridotite of the Shimian ophiolite. The scale bar is 100 μm .

Figure 10. Plots of TiO_2 vs. Al_2O_3 , $\text{Cr}/(\text{Cr}+\text{Al})$ vs. $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$, Cr_2O_3 vs. TiO_2 and Cr-Al-Fe^{3+} for chromites from the serpentinized peridotite of the Shimian ophiolite (after Wang et al., 2005 and references therein).

826 Figure 11. Plots of Ti/Sc vs. Ti/V and La/Sm vs. Sm/Yb for rocks from the gabbro
827 unit and mafic dikes of the Shimian ophiolite. Boninite, siliceous high-magnesian
828 basalt and MORB are shown for comparison (Zhao and Asimow, 2014; Piercey
829 et al., 2001 and references therein). Partial melting curves of the depleted mantle
830 and the primitive mantle are from Zhao and Asimow (2014).

831

832 Figure 12. Neoproterozoic Andean-type arc system in the new reconstructed
833 supercontinent Rodinia. The thick black lines represent rift margins.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Table 1. Zircon U-Pb dating for the gabbros and dikes from the Shimian ophiolite.

Spot	U	Th	Th/U	Ratios corrected common Pb						Ages (Ma)					
				$^{206}\text{Pb}/^{238}\text{U}$	$\pm 1\sigma$	$^{207}\text{Pb}/^{235}\text{U}$	$\pm 1\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm 1\sigma$	$^{206}\text{Pb}/^{238}\text{U}$	$\pm 1\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$	$\pm 1\sigma$	$^{208}\text{Pb}/^{232}\text{Th}$	$\pm 1\sigma$
Sample SM137 from the gabbro unit															
SM137-1	49	39	0.80	0.1355	0.0026	1.6345	0.2253	0.0875	0.0117	819	15	1371	261	861	89
SM137-2	137	107	0.79	0.1020	0.0012	0.8723	0.0526	0.0620	0.0036	626	7	674	124	684	25
SM137-3	117	112	0.96	0.1217	0.0014	0.9931	0.0612	0.0592	0.0035	741	8	573	129	723	24
SM137-4	36	42	1.16	0.1341	0.0023	1.1556	0.1341	0.0625	0.0070	811	13	692	242	799	43
SM137-5	162	173	1.07	0.1368	0.0020	1.1362	0.0493	0.0602	0.0024	826	11	612	84	756	21
SM137-6	251	311	1.24	0.0411	0.0004	0.2934	0.0220	0.0518	0.0038	260	3	276	167	250	8
SM137-7	358	381	1.06	0.1143	0.0013	0.9840	0.0373	0.0624	0.0022	698	7	689	74	804	16
SM137-8	593	431	0.73	0.0960	0.0008	0.8126	0.0218	0.0614	0.0015	591	4	653	53	523	11
SM137-9	38	23	0.61	0.1298	0.0023	0.9480	0.1429	0.0530	0.0078	787	13	327	304	652	79
SM137-10	36	27	0.74	0.1404	0.0023	1.2834	0.1360	0.0663	0.0068	847	13	815	216	834	63
SM137-11	79	80	1.02	0.1334	0.0016	1.1542	0.0742	0.0628	0.0039	807	9	700	132	798	28
SM137-12	38	34	0.90	0.1348	0.0020	1.3781	0.0396	0.0741	0.0017	815	12	1045	46	872	23
SM137-13	572	370	0.65	0.1274	0.0010	1.1603	0.0307	0.0660	0.0016	773	6	807	51	747	16
SM137-14	515	272	0.53	0.1248	0.0012	1.1048	0.0219	0.0642	0.0011	758	7	748	35	726	14
SM137-15	36	27	0.75	0.1232	0.0025	1.0026	0.2130	0.0590	0.0123	749	14	567	463	696	97
Sample SM140 from the gabbro unit															
SM140-1.1	55	63	1.14	0.1353	0.0041	1.1000	0.1056	0.0592	0.0054	818	23	574	200	772	42
SM140-1.2	77	72	0.94	0.1367	0.0041	1.0300	0.0958	0.0547	0.0048	826	23	398	200	787	43
SM140-2	74	107	1.45	0.1365	0.0042	1.1500	0.1495	0.0612	0.0080	825	24	645	270	803	45
SM140-3	69	89	1.29	0.1330	0.0040	0.9600	0.0960	0.0523	0.0050	805	22	300	220	757	44
SM140-4	113	133	1.18	0.1283	0.0037	0.9630	0.0636	0.0545	0.0033	778	21	390	130	749	30
SM140-5	106	86	0.81	0.1291	0.0037	1.0800	0.0605	0.0606	0.0029	783	21	626	100	777	34
SM140-6	105	153	1.46	0.1288	0.0037	1.0350	0.0942	0.0583	0.0051	781	22	539	190	753	33
SM140-7	63	62	0.99	0.1264	0.0039	0.8300	0.0996	0.0475	0.0057	767	22	77	280	724	44
SM140-8	190	131	0.69	0.0421	0.0013	0.2720	0.0215	0.0469	0.0034	266	8	42	170	243	15
SM140-9	51	31	0.62	0.1453	0.0044	1.5180	0.0638	0.0758	0.0023	874	25	1,089	60	917	43
SM140-10	1112	1135	1.02	0.0434	0.0013	0.3180	0.0572	0.0532	0.0090	274	8	338	390	242	18

SM140-13	60	53	0.89	0.1306	0.0040	1.0100	0.1111	0.0560	0.0062	791	23	452	230	716	49
SM140-14	2512	1990	0.79	0.0409	0.0011	0.2705	0.0095	0.0480	0.0011	259	7	97	53	303	27
SM140-15	2425	5090	2.10	0.0383	0.0010	0.2560	0.0102	0.0485	0.0014	242.1	7	122	67	69.5	3.2
SM140-16	2450	1395	0.57	0.0445	0.0012	0.2920	0.0117	0.0476	0.0013	280.7	8	79	68	533	130
Sample SM48 from the gabbro unit															
SM48-1	312	502	0.62	0.1358	0.0014	1.4412	0.0461	0.0765	0.0024	821	8	1109	64	924	24
SM48-2	310	492	0.63	0.1345	0.0014	1.1874	0.0341	0.0637	0.0018	813	8	731	59	804	18
SM48-3	300	422	0.71	0.1761	0.0019	1.7905	0.0473	0.0736	0.0019	1046	10	1031	54	1080	24
SM48-4	724	1696	0.43	0.1360	0.0012	1.2287	0.0239	0.0651	0.0012	822	7	776	36	808	14
SM48-5	1028	2212	0.46	0.1297	0.0010	1.1507	0.0217	0.0638	0.0012	786	6	744	41	777	13
SM48-6	1294	2326	0.56	0.1367	0.0012	1.2364	0.0266	0.0650	0.0014	826	7	774	45	815	15
SM48-7	570	579	0.99	0.1271	0.0013	1.1640	0.0338	0.0658	0.0019	772	8	1200	61	780	17
SM48-8	251	178	1.41	0.1737	0.0021	1.8435	0.0597	0.0773	0.0027	1033	12	1128	69	1056	22
SM48-9	591	997	0.59	0.1323	0.0013	1.2215	0.0297	0.0662	0.0016	801	7	813	50	810	17
SM48-10	292	576	0.51	0.1348	0.0015	1.2418	0.0338	0.0665	0.0018	815	9	820	56	817	19
SM48-11	1590	2017	0.79	0.1345	0.0015	1.2610	0.0298	0.0673	0.0016	814	8	856	48	812	18
SM48-12	497	892	0.56	0.1337	0.0017	1.5346	0.0792	0.0801	0.0034	809	10	1200	83	988	43
SM48-13	791	1393	0.57	0.1267	0.0016	1.1721	0.0333	0.0664	0.0019	769	9	820	59	775	22
SM48-14	1284	1354	0.95	0.1289	0.0013	1.1917	0.0302	0.0664	0.0017	782	8	820	53	794	19
SM48-15	3072	5774	0.53	0.1319	0.0013	1.2797	0.0259	0.0698	0.0014	799	7	920	41	830	19
SM48-16	653	1057	0.62	0.1448	0.0024	1.3258	0.0388	0.0661	0.0017	872	13	809	47	917	28
SM48-17	937	1534	0.61	0.1423	0.0016	1.3226	0.0303	0.0670	0.0014	858	9	839	46	895	20
SM48-18	698	1810	0.39	0.1314	0.0013	1.2001	0.0274	0.0658	0.0014	796	7	800	45	812	17
SM48-19	132	177	0.74	0.1694	0.0021	1.6986	0.0644	0.0730	0.0028	1009	11	1013	84	1044	30
SM48-20	1335	2798	0.48	0.1314	0.0010	1.2289	0.0222	0.0674	0.0012	796	6	850	36	803	14
SM48-21	398	1016	0.39	0.1349	0.0019	1.2851	0.0362	0.0687	0.0016	816	11	889	50	829	22
SM48-22	310	337	0.92	0.1714	0.0019	1.7719	0.0478	0.0749	0.0019	1020	11	1065	52	990	21
SM48-23	498	1114	0.45	0.1366	0.0017	1.2765	0.0313	0.0677	0.0015	825	10	857	48	800	19
SM48-24	57	92	0.62	0.1706	0.0027	1.8288	0.0856	0.0788	0.0037	1015	15	1166	62	989	36
SM48-25	172	182	0.94	0.1685	0.0021	1.8048	0.0683	0.0785	0.0031	1004	12	1161	78	981	26
SM48-26	310	328	0.94	0.1758	0.0018	1.8609	0.0518	0.0764	0.0020	1044	10	1106	56	994	21
SM48-27	947	1942	0.49	0.1394	0.0012	1.3270	0.0278	0.0685	0.0013	841	7	887	34	811	15
SM48-28	1859	1710	1.09	0.1307	0.0009	1.2322	0.0233	0.0680	0.0013	792	5	878	39	699	11

Sample SM18 from the mafic dike

SM18-1	114	132	1.19	0.1264	0.0021	1.0310	0.0371	0.0591	0.0019	767	12	572	71	698	16
SM18-2	242	205	0.88	0.1262	0.0019	1.1730	0.0246	0.0674	0.0009	766	11	850	29	767	16
SM18-3	129	84	0.67	0.1377	0.0022	1.2830	0.0282	0.0676	0.0010	832	12	857	31	795	16
SM18-4	102	100	1.02	0.1271	0.0020	1.1300	0.0316	0.0645	0.0015	771	12	758	49	737	16
SM18-5	140	107	0.79	0.1366	0.0022	1.2490	0.0300	0.0663	0.0012	825	12	817	38	786	17
SM18-6	239	274	1.18	0.1350	0.0020	1.2090	0.0254	0.0649	0.0009	816	11	772	30	764	13
SM18-7	83	93	1.15	0.1285	0.0021	1.1070	0.0310	0.0625	0.0014	779	12	692	50	751	16
SM18-8	353	294	0.86	0.1406	0.0021	1.2500	0.0263	0.0645	0.0009	848	12	758	30	1008	17
SM18-9	222	165	0.77	0.1333	0.0020	1.2350	0.0222	0.0672	0.0007	807	11	844	23	770	13
SM18-10	878	849	1.00	0.1163	0.0017	1.0210	0.0204	0.0636	0.0009	709	10	730	29	669	12
SM18-11	386	535	1.43	0.1280	0.0019	1.1630	0.0209	0.0659	0.0007	776	11	803	22	729	12
SM18-12	256	287	1.16	0.1280	0.0019	1.1360	0.0204	0.0644	0.0007	777	11	754	23	755	12
SM18-13	237	246	1.07	0.1360	0.0020	1.2000	0.0252	0.0640	0.0010	822	11	742	31	1630	31
SM18-14	232	173	0.77	0.1370	0.0021	1.2380	0.0260	0.0655	0.0009	828	11	792	30	785	15
SM18-15	187	205	1.13	0.1283	0.0019	1.1470	0.0229	0.0648	0.0009	778	11	769	29	760	13
SM18-17	255	314	1.27	0.1376	0.0021	1.2160	0.0243	0.0641	0.0009	831	11	745	30	814	13
SM18-18	179	174	1.00	0.1426	0.0021	1.2820	0.0308	0.0652	0.0012	860	12	781	40	885	17
SM18-19	260	322	1.28	0.1364	0.0020	1.2290	0.0270	0.0653	0.0010	824	11	784	34	768	13
SM18-20	181	150	0.86	0.1389	0.0025	1.2090	0.0290	0.0632	0.0010	838	14	714	33	855	18
SM18-21	164	141	0.89	0.1400	0.0021	1.2330	0.0284	0.0639	0.0011	845	12	737	36	864	17

Table 2. Zircon Lu-Hf isotopes for the gabbro and dike from the Shimian ophiolite.

	$^{176}\text{Yb}/^{177}\text{Hf}$ 1 σ		$^{176}\text{Lu}/^{177}\text{Hf}$ 1 σ		$^{176}\text{Hf}/^{177}\text{Hf}$ 1 σ		$^{176}\text{Hf}/^{177}\text{Hf}(\text{i})$	εHf	1 σ
Sample SM48 from the gabbro unit									
SM48-01	0.017115	0.000358	0.000615	0.000011	0.282247	0.000012	0.282238	-1.25	0.43
SM48-02	0.014449	0.000164	0.000576	0.000007	0.282257	0.000013	0.282248	-0.89	0.47
SM48-03	0.014395	0.000258	0.000610	0.000015	0.282513	0.000031	0.282504	8.17	1.08
SM48-04	0.032830	0.000972	0.001315	0.000039	0.282254	0.000011	0.282234	-1.38	0.38
SM48-05	0.017584	0.000126	0.000738	0.000005	0.282240	0.000011	0.282229	-1.55	0.37
SM48-06	0.029797	0.000188	0.001178	0.000007	0.282257	0.000012	0.282239	-1.19	0.41
SM48-07	0.040708	0.002450	0.001722	0.000097	0.282467	0.000013	0.282441	5.96	0.45
SM48-08	0.034047	0.000174	0.001332	0.000005	0.282527	0.000019	0.282507	8.29	0.67
SM48-09	0.019544	0.000248	0.000778	0.000009	0.282236	0.000012	0.282224	-1.73	0.42
SM48-10	0.013633	0.000133	0.000534	0.000005	0.282232	0.000012	0.282224	-1.75	0.41
SM48-11	0.029526	0.000403	0.001149	0.000015	0.282254	0.000020	0.282237	-1.28	0.70
SM48-12	0.015858	0.000138	0.000635	0.000006	0.282255	0.000010	0.282246	-0.96	0.35
SM48-13	0.022709	0.000212	0.000938	0.000008	0.282243	0.000010	0.282229	-1.56	0.36
SM48-14	0.025460	0.000921	0.000938	0.000035	0.282285	0.000016	0.282271	-0.07	0.57
SM48-15	0.026182	0.000478	0.001087	0.000021	0.282247	0.000013	0.282231	-1.50	0.45
SM48-16	0.013420	0.000140	0.000564	0.000006	0.282265	0.000012	0.282257	-0.57	0.43
SM48-17	0.042566	0.000165	0.001722	0.000006	0.282344	0.000013	0.282318	1.59	0.46
SM48-18	0.020930	0.000746	0.000883	0.000032	0.282235	0.000011	0.282222	-1.80	0.38
SM48-19	0.020767	0.000229	0.000842	0.000008	0.282502	0.000008	0.282489	7.66	0.28
SM48-20	0.026805	0.000525	0.001106	0.000023	0.282238	0.000014	0.282222	-1.81	0.50
SM48-21	0.015591	0.000776	0.000614	0.000033	0.282230	0.000020	0.282221	-1.83	0.72
SM48-22	0.026371	0.000055	0.001026	0.000002	0.282515	0.000013	0.282500	8.04	0.46
SM48-23	0.019926	0.000619	0.000819	0.000025	0.282237	0.000012	0.282225	-1.70	0.41
SM48-24	0.007908	0.000028	0.000335	0.000001	0.282480	0.000010	0.282475	7.16	0.36
SM48-25	0.041477	0.000068	0.001648	0.000002	0.282522	0.000010	0.282497	7.94	0.37
SM48-26	0.051144	0.000192	0.001941	0.000007	0.282520	0.000014	0.282491	7.72	0.48
SM48-27	0.021423	0.000172	0.000852	0.000006	0.282254	0.000012	0.282241	-1.14	0.40
SM48-28	0.017427	0.000314	0.000712	0.000012	0.282263	0.000015	0.282253	-0.72	0.53
Sample SM18 from the mafic dike									
SM18-1	0.012301	0.000372	0.000493	0.000013	0.282467	0.000013	0.282459	6.60	0.47
SM18-2	0.027305	0.000134	0.001045	0.000004	0.282367	0.000013	0.282351	2.78	0.45
SM18-3	0.028044	0.001660	0.001084	0.000063	0.282323	0.000014	0.282306	1.18	0.48
SM18-4	0.010809	0.000132	0.000436	0.000005	0.282431	0.000012	0.282425	5.37	0.41
SM18-5	0.023821	0.000174	0.000938	0.000006	0.282332	0.000016	0.282318	1.58	0.55
SM18-6	0.059714	0.001317	0.002489	0.000060	0.282523	0.000018	0.282486	7.55	0.64
SM18-7	0.017679	0.001102	0.000770	0.000045	0.282564	0.000012	0.282553	9.90	0.43
SM18-8	0.052782	0.001248	0.002086	0.000043	0.282514	0.000015	0.282482	7.41	0.52
SM18-9	0.010963	0.000069	0.000512	0.000002	0.282416	0.000015	0.282408	4.80	0.51
SM18-10	0.022949	0.000547	0.000955	0.000023	0.282424	0.000014	0.282409	4.83	0.47
SM18-11	0.090789	0.000815	0.003498	0.000028	0.282627	0.000019	0.282575	10.69	0.67
SM18-12	0.024383	0.000413	0.001002	0.000014	0.282432	0.000017	0.282417	5.11	0.58
SM18-13	0.060892	0.000762	0.002500	0.000035	0.282479	0.000018	0.282441	5.96	0.64
SM18-14	0.024966	0.000157	0.000982	0.000007	0.282390	0.000014	0.282375	3.61	0.48
SM18-15	0.079609	0.001027	0.003095	0.000040	0.282614	0.000017	0.282568	10.45	0.60
SM18-17	0.035190	0.002703	0.001451	0.000099	0.282584	0.000013	0.282563	10.26	0.45
SM18-18	0.042368	0.001289	0.001707	0.000050	0.282556	0.000018	0.282530	9.11	0.63
SM18-19	0.095672	0.000710	0.003726	0.000026	0.282584	0.000020	0.282528	9.02	0.70
SM18-20	0.026845	0.000583	0.001140	0.000021	0.282476	0.000017	0.282459	6.58	0.59
SM18-21	0.022849	0.000656	0.000968	0.000022	0.282494	0.000015	0.282479	7.32	0.51

Table 3. Major and trace elements for the rocks from the Shimian ophiolite.

Peridotite											
Sample	SM-1	SM-4	SM-8	SM-29	SM-35	SM134	SM135	SM136	SM138	SM143	SM144
Major element (wt.%)											
SiO ₂	41.95	41.24	40.80	40.38	40.34	38.04	38.20	37.65	38.21	39.09	39.17
TiO ₂	0.03	0.04	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
Al ₂ O ₃	0.54	0.45	0.33	0.37	0.32	0.53	0.63	0.57	0.42	0.75	0.76
Fe ₂ O ₃	7.23	8.02	8.25	8.17	8.60	7.79	8.01	8.44	8.18	6.81	6.65
MnO	0.11	0.09	0.09	0.07	0.10	0.07	0.10	0.08	0.06	0.09	0.12
MgO	38.74	37.74	37.62	35.29	36.94	39.71	39.10	38.53	39.26	39.20	38.95
CaO	0.09	0.10	0.19	0.14	0.09	0.12	0.77	0.08	0.36	0.11	0.11
Na ₂ O	0.04	0.05	0.05	0.07	0.05	0.01	0.01	0.02	0.01	0.03	0.02
K ₂ O	0.01	0.01	0.02	0.02	0.01	0.01	0.00	0.01	0.00	0.03	0.01
P ₂ O ₅	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
LOI	11.20	12.05	12.31	15.33	13.29	14.07	14.03	13.62	13.93	13.38	13.39
Total	99.94	99.79	99.69	99.87	99.78	100.36	100.85	99.01	100.44	99.50	99.19
Trace element (ppm)											
Li	0.39	0.35	0.31	9.77	0.32	0.23	0.17	0.00	0.03	0.20	0.39
Sc	9.46	8.39	8.68	9.86	9.51	6.04	7.48	6.64	5.12	8.26	8.17
V	29.4	32.8	30.3	33.6	30.4	23.9	27.8	23.2	19.9	19.6	31.2
Cr	1730	1530	1520	1660	1320	468	2292	1355	631	1296	1682
Co	100	107	106	91.7	106	123	238	139	158	81	84
Ni	1709	1573	1573	1683	1717	2294	2352	1837	2244	1848	1776
Rb	0.17	0.09	0.18	2.87	0.05	0.17	0.13	0.11	0.12	0.19	0.29
Sr	4.87	4.12	3.25	8.88	0.96	2.51	8.43	1.32	3.54	1.29	1.82
Y	0.16	0.74	0.08	0.23	0.20	0.15	0.05	0.13	0.05	0.07	0.08
Zr	0.38	1.97	0.66	0.82	0.42	0.82	0.23	0.18	0.19	0.21	0.36
Nb	0.23	0.25	0.11	0.09	0.17	0.07	0.03	0.04	0.02	0.01	0.02
Sb	0.6	1.06	1.17	0.73	0.94	5.28	4.22	4.79	4.80	3.10	5.48
Cs	0.04	0.02	0.02	9.16	0.01	0.15	0.44	0.27	0.10	0.14	0.66
Ba	2.32	1.29	2.10	3.20	2.12	1.91	1.89	0.60	1.14	0.45	1.77
La	0.07	0.11	0.13	0.15	0.07	0.23	0.17	0.23	0.14	0.02	0.04
Ce	0.09	0.19	0.23	0.24	0.12	0.45	0.29	0.47	0.24	0.04	0.11
Pr	0.01	0.02	0.02	0.02	0.02	0.05	0.03	0.06	0.02	0.01	0.02
Nd	0.04	0.08	0.07	0.05	0.08	0.19	0.09	0.23	0.07	0.01	0.05
Sm	0.01	0.03	0.02	0.01	0.02	0.05	0.02	0.04	0.01	0.01	0.01
Eu	0.02	0.02	0.00	0.11	0.01	0.02	0.02	0.02	0.01	0.01	0.00
Gd	0.01	0.05	0.01	0.01	0.03	0.04	0.01	0.03	0.01	0.01	0.01
Tb	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Dy	0.01	0.09	0.01	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.01
Ho	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Er	0.01	0.08	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Tm	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yb	0.01	0.09	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.02
Lu	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hf	0.01	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-0.01
Ta	0.18	0.12	0.05	0.06	0.07	0.01	0.00	0.00	0.00	0.00	0.00
Pb	1.35	1.64	3.07	9.39	1.97	3.85	2.05	1.89	3.49	0.74	1.53
Th	0.01	0.02	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
U	0.02	0.03	0.04	0.02	0.03	0.01	0.03	0.01	0.01	0.00	0.00

Table 3 (continued)

		Gabbro							Dike		
SM145	SM146	SM-43	SM-44	SM-45	SM-47	SM-48	SM139	SM142	SM-11	SM-13	SM-14
Major element (wt.%)											
39.26	36.88	47.84	45.21	50.34	50.99	51.18	49.18	49.10	41.39	37.31	40.96
0.01	0.01	0.46	0.71	0.58	0.37	0.45	0.33	0.36	1.01	1.19	1.08
0.81	0.39	14.37	14.28	15.06	14.60	13.67	14.99	16.15	12.41	13.60	13.17
7.00	8.41	8.85	10.90	9.49	7.60	8.17	7.77	7.63	7.67	8.10	8.34
0.11	0.10	0.14	0.11	0.15	0.16	0.16	0.15	0.16	0.12	0.18	0.13
39.22	40.25	8.18	6.46	7.99	8.82	9.81	10.34	8.60	8.49	7.75	9.82
0.04	0.04	9.45	17.44	10.12	8.67	8.84	14.86	14.62	22.47	24.88	19.70
0.02	0.01	2.45	0.24	2.42	2.43	2.80	1.55	2.04	0.08	0.00	0.02
0.00	0.00	0.56	0.05	0.59	1.51	0.70	0.14	0.18	0.02	0.01	0.02
0.00	0.00	0.02	0.03	0.02	0.02	0.02	0.00	0.00	0.23	0.28	0.23
13.27	13.75	7.05	4.43	3.09	4.55	3.63	1.03	1.16	5.50	6.34	6.20
99.73	99.85	99.37	99.85	99.85	99.72	99.42	100.34	100.02	99.40	99.65	99.65
Trace element (ppm)											
0.14	0.06	47.3	4.75	43.1	62.0	79.8	22.8	20.4	51.6	54.9	78.0
8.14	6.04	37.2	36.2	38.9	33.7	40.6	53.5	39.5	30.0	32.7	29.3
32.0	21.2	282	483	297	226	249	225	201	191	205	199
1562	1306	142	129	201	237	256	756	437	402	256	386
84	103	37.9	41.6	38.2	36.1	38.5	41.6	37.8	41.2	37.1	42.5
1865	2306	107	103	106	136	149	160	126	181	145	167
0.20	0.12	22.9	0.77	24.9	101	47.2	8.86	8.19	1.63	0.53	0.59
1.14	0.84	123	264	100	137	106	61.9	115	34.0	9.3	53.4
0.06	0.11	13.7	16.9	18.7	12.8	13.2	10.1	11.7	24.1	26.7	23.6
1.03	0.23	13.4	20.4	24.7	18.1	20.1	6.2	19.8	136	155	134
0.01	0.01	0.37	0.38	0.26	0.15	0.24	0.07	0.40	7.39	8.78	7.11
4.90	4.69	1.01	4.20	0.95	0.50	0.62	2.97	2.72	0.14	0.15	0.18
0.40	0.22	2.92	0.22	1.84	12.4	3.98	1.99	1.07	0.84	0.96	0.49
0.69	0.50	56.1	6.18	42.8	125	61.6	9.20	18.0	51.2	7.81	17.2
0.02	0.16	0.39	0.88	0.57	0.45	0.45	0.27	0.52	15.0	19.0	16.0
0.05	0.31	1.41	2.49	2.23	1.58	1.56	0.93	1.72	35.6	44.9	38.9
0.01	0.03	0.33	0.47	0.49	0.33	0.33	0.19	0.32	4.3	5.1	4.16
0.02	0.10	2.14	2.84	3.19	2.03	2.12	1.28	2.05	18.1	21.3	17.6
0.01	0.01	1.00	1.18	1.37	0.85	0.90	0.71	0.90	4.01	4.57	3.85
0.00	0.04	0.49	0.58	0.64	0.38	0.45	0.36	0.42	1.12	1.37	1.18
0.01	0.02	1.68	1.98	2.28	1.49	1.61	1.06	1.28	3.95	4.49	3.94
0.00	0.00	0.30	0.35	0.41	0.26	0.29	0.23	0.27	0.63	0.72	0.62
0.01	0.01	2.17	2.52	2.90	1.85	2.07	1.63	2.11	3.67	4.18	3.61
0.00	0.00	0.48	0.55	0.64	0.41	0.45	0.38	0.48	0.74	0.84	0.73
0.00	0.01	1.43	1.65	1.88	1.22	1.37	1.17	1.44	2.13	2.46	2.11
0.00	0.00	0.22	0.25	0.29	0.18	0.20	0.16	0.18	0.29	0.34	0.30
0.01	0.02	1.45	1.66	1.91	1.21	1.32	1.10	1.32	1.93	2.29	1.95
0.00	0.00	0.22	0.25	0.29	0.18	0.20	0.16	0.20	0.28	0.33	0.28
0.01	-0.01	0.50	0.60	0.73	0.51	0.52	0.26	0.64	2.77	3.26	2.80
0.00	0.00	0.14	0.06	0.03	0.03	0.07	0.01	0.03	0.44	0.53	0.48
3.14	0.75	3.00	6.23	2.91	44.1	6.19	3.19	12.39	3.72	1.83	1.15
0.01	0.00	0.02	0.02	0.03	0.01	0.01	0.02	0.06	1.74	2.22	1.73
0.00	0.00	0.02	0.03	0.03	0.02	0.02	0.00	0.02	0.38	0.46	0.37

Table 3 (continued)

SM-15	SM-17	SM-18	SM-21	SM-22	SM-24	SM-25	SM-26	SM-28	SM-30
Major element (wt.%)									
40.74	38.07	38.70	38.24	44.72	45.06	43.65	44.15	44.53	44.08
1.05	1.05	1.21	0.96	1.10	1.03	1.05	1.05	0.91	1.99
12.21	11.75	10.84	14.81	16.16	15.68	14.94	15.12	15.61	14.43
9.01	8.33	9.02	8.21	9.79	9.68	9.03	9.19	9.00	11.80
0.13	0.16	0.16	0.30	0.13	0.15	0.19	0.17	0.15	0.17
10.39	9.86	11.18	6.86	8.13	8.03	7.43	7.50	8.16	6.45
18.66	22.44	21.25	23.40	8.21	10.34	15.00	13.75	10.82	8.66
0.04	0.00	0.00	0.06	1.76	1.75	0.92	1.31	1.46	1.92
0.02	0.02	0.02	0.05	2.99	1.87	0.74	0.62	2.37	3.10
0.23	0.24	0.27	0.11	0.09	0.09	0.11	0.11	0.08	0.31
7.45	8.03	7.27	7.02	7.07	6.18	6.22	6.19	7.00	6.55
99.94	99.95	99.91	100.01	100.15	99.84	99.27	99.15	100.08	99.47
Trace element (ppm)									
81.3	58.9	67.8	76	180	110	96.1	96.8	135	120
30.9	32.3	28.4	31.1	29.4	28.9	30.2	30.3	30.7	31.6
191	199	212	193	223	209	187	202	101	262
431	400	412	157	162	151	156	159	141	146
47.3	42.9	44.3	39.3	46	44.7	42.5	42.6	42.5	40.5
215	188	188	83.8	107	111	116	109	114	73.4
0.72	0.75	0.84	7.86	335	248	89	70	128	392
35.0	19.3	16.8	27.0	476	1155	476	690	567	792
23.5	23.9	26.4	26.5	28.4	26.7	26.9	28.0	11.0	39.0
133	136	146	94.7	78.7	73.7	94.8	94.9	30.1	170
7.09	7.36	8.41	2.69	1.32	1.24	2.75	2.66	1.25	7.82
0.15	0.62	0.19	0.36	0.25	0.25	0.15	0.18	0.13	0.25
0.51	1.91	2.16	3.47	51	32.7	17.1	14.1	48.1	68.6
28.5	15.6	13.6	18.5	509	405	212	331	197	487
16.9	16.5	18.4	7.40	4.25	4.02	7.13	7.34	1.39	12.0
39.5	40.2	45.3	18.8	13.0	12.0	19.4	19.0	3.90	28.7
4.22	4.24	4.91	2.02	1.62	1.49	2.19	2.13	1.32	4.48
17.9	17.9	20.6	9.94	8.51	7.83	10.4	10.2	7.11	21.4
3.82	3.97	4.43	2.90	2.80	2.67	3.03	2.99	2.33	5.75
1.00	1.16	1.34	1.18	0.92	1.10	1.12	1.06	1.09	1.96
3.79	3.85	4.55	3.72	4.01	3.65	3.95	3.92	3.34	6.56
0.61	0.62	0.71	0.62	0.65	0.60	0.64	0.64	0.54	1.06
3.55	3.61	4.06	4.05	4.31	3.98	4.10	4.09	3.59	6.71
0.72	0.72	0.82	0.84	0.90	0.81	0.85	0.85	0.74	1.37
2.10	2.12	2.41	2.42	2.58	2.35	2.46	2.50	2.14	3.98
0.29	0.30	0.33	0.34	0.37	0.34	0.36	0.36	0.31	0.56
1.95	1.96	2.23	2.19	2.46	2.22	2.34	2.33	1.99	3.66
0.29	0.29	0.33	0.34	0.36	0.33	0.35	0.34	0.29	0.54
2.77	2.85	3.19	2.18	1.94	1.84	2.28	2.25	1.62	4.10
0.45	0.44	0.54	0.18	0.11	0.11	0.19	0.28	0.10	0.44
3.60	2.51	2.74	8.73	49.7	35.8	6.75	3.87	2.76	17.7
1.76	1.78	2.02	0.81	0.31	0.29	0.80	0.70	0.25	0.69
0.37	0.38	0.43	0.16	0.08	0.08	0.17	0.14	0.07	0.16

Table 4. Chemical composition of representative chromite grains in the serpentinized peridotite from the Shimian ophiolite.

Sample	SM10					SM39													
Grain	SM10-1			SM10-2		SM39-3						SM39-4					SM39-7		
Type	r	c	c	c	r	r	m	c	c	m	r	r	m	c	m	r	r	m	c
Number	10	15	21	29	32	62	69	79	80	86	94	99	103	108	109	110	149	153	155
SiO ₂	0.04	0.04	0.01	0.04	0.04	0.02	0.03	0.01	0.00	0.03	0.03	0.03	0.00	0.03	0.03	0.03	0.04	0.05	0.03
TiO ₂	0.02	0.00	0.00	0.02	0.00	0.20	0.23	0.20	0.19	0.19	0.20	0.23	0.21	0.24	0.23	0.22	0.19	0.20	0.21
Al ₂ O ₃	20.12	22.43	22.05	21.98	17.03	23.43	22.70	22.62	22.63	22.84	22.06	23.10	23.20	22.97	22.73	23.12	20.62	21.27	21.06
Cr ₂ O ₃	49.24	47.46	46.80	46.75	51.13	42.30	42.92	43.99	43.85	43.71	43.86	43.83	44.32	44.25	44.41	44.07	41.76	42.83	42.98
FeO	19.87	18.86	20.74	18.49	21.00	21.07	21.18	19.60	20.76	20.27	20.51	20.00	19.99	19.92	19.46	19.87	25.92	24.48	24.29
MnO	0.70	0.67	0.53	0.70	0.60	0.77	0.99	0.61	1.03	0.82	0.66	0.75	0.65	0.85	0.79	0.71	0.65	0.43	0.43
MgO	9.82	10.81	9.62	11.23	9.41	10.98	10.84	11.87	10.75	11.13	11.60	11.12	11.41	11.12	11.27	11.14	9.79	10.22	10.17
Totals	99.80	100.25	99.76	99.21	99.20	98.77	98.89	98.92	99.20	98.99	98.91	99.07	99.78	99.39	98.93	99.16	98.98	99.47	99.17
Si	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001
Al ^{VI}	0.752	0.822	0.819	0.812	0.650	0.864	0.840	0.831	0.836	0.842	0.814	0.851	0.847	0.844	0.839	0.851	0.773	0.790	0.785
Fe ³⁺	0.009	0.008	0.013	0.027	0.038	0.079	0.083	0.074	0.069	0.065	0.089	0.054	0.057	0.052	0.050	0.050	0.165	0.130	0.128
Ti	0.000	0.000	0.000	0.000	0.000	0.005	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.005	0.005
Cr	1.235	1.167	1.167	1.158	1.309	1.046	1.065	1.084	1.086	1.081	1.085	1.083	1.086	1.091	1.099	1.088	1.050	1.067	1.075
Fe ²⁺	0.518	0.483	0.534	0.458	0.530	0.473	0.473	0.437	0.475	0.465	0.447	0.469	0.461	0.467	0.459	0.469	0.524	0.515	0.515
Mn	0.019	0.018	0.014	0.019	0.017	0.020	0.026	0.016	0.027	0.022	0.017	0.020	0.017	0.023	0.021	0.019	0.018	0.011	0.012
Mg	0.465	0.501	0.452	0.525	0.454	0.512	0.507	0.552	0.502	0.519	0.541	0.518	0.527	0.517	0.526	0.518	0.464	0.480	0.480
Σ Cation	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Σ O	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Mg#	47.28	50.94	45.87	53.39	46.12	52.00	51.74	55.81	51.37	52.74	54.74	52.49	53.35	52.52	53.38	52.49	46.98	48.26	48.23
Cr#	62.14	58.67	58.74	58.79	66.83	54.77	55.92	56.61	56.52	56.22	57.15	56.00	56.16	56.37	56.72	56.12	57.60	57.47	57.79

Mg#=100Mg/(Mg+Fe²⁺); and Cr#=100Cr/(Cr+Al).

c=core; m=mantle; r=rim.

Table 4 (continued)

		SM39-8					SM39-10					SM42			SM42-2				
m	r	r	m	c	m	r	r	m	c	m	r	SM42-1			SM42-2				
160	163	168	170	172	175	177	202	205	208	211	213	237	240	242	249	253	257	260	262
0.04	0.06	0.09	0.03	0.06	0.11	0.17	0.13	0.01	0.02	0.03	0.12	0.14	0.10	0.03	0.02	0.02	0.02	0.10	0.04
0.21	0.17	0.17	0.17	0.17	0.18	0.14	0.31	0.22	0.20	0.20	0.19	0.02	0.01	0.02	0.04	0.03	0.03	0.02	0.03
20.97	20.20	22.56	22.15	22.73	21.96	22.92	20.07	20.58	20.99	20.79	20.76	22.22	22.75	21.86	19.56	19.64	20.80	21.99	22.85
42.52	41.95	41.49	41.73	41.95	41.65	40.93	42.21	43.07	43.45	43.18	43.13	44.39	44.59	45.46	48.23	48.02	46.72	45.36	45.11
24.96	26.24	23.83	22.58	22.64	22.56	23.48	25.07	24.38	23.70	24.12	25.24	19.58	21.15	21.35	20.55	21.25	20.05	20.38	20.53
0.43	0.53	0.81	0.73	0.65	0.71	0.76	1.18	0.77	0.43	0.54	0.73	0.75	0.46	0.56	0.82	0.51	0.80	0.52	0.62
9.81	9.34	10.47	11.56	11.30	11.48	10.14	10.08	10.26	10.85	10.66	9.56	11.66	10.24	10.52	10.45	10.34	11.20	11.47	10.86
98.93	98.50	99.41	98.96	99.50	98.64	98.54	99.06	99.29	99.63	99.51	99.72	98.77	99.30	99.80	99.67	99.80	99.62	99.84	100.05
0.001	0.002	0.003	0.001	0.002	0.003	0.005	0.004	0.000	0.001	0.001	0.004	0.005	0.003	0.001	0.001	0.000	0.000	0.003	0.001
0.786	0.764	0.832	0.816	0.833	0.812	0.853	0.752	0.767	0.776	0.771	0.774	0.820	0.842	0.807	0.730	0.733	0.769	0.806	0.837
0.134	0.160	0.127	0.143	0.124	0.140	0.109	0.164	0.144	0.135	0.144	0.130	0.072	0.044	0.064	0.058	0.063	0.070	0.072	0.051
0.005	0.004	0.004	0.004	0.004	0.004	0.003	0.007	0.005	0.005	0.005	0.005	0.001	0.000	0.000	0.001	0.001	0.001	0.000	0.001
1.069	1.064	1.027	1.031	1.031	1.033	1.021	1.061	1.078	1.078	1.074	1.079	1.099	1.107	1.126	1.208	1.202	1.159	1.115	1.108
0.530	0.545	0.497	0.447	0.465	0.452	0.511	0.502	0.501	0.487	0.491	0.538	0.441	0.511	0.495	0.486	0.499	0.456	0.458	0.483
0.012	0.014	0.021	0.019	0.017	0.019	0.020	0.032	0.021	0.011	0.014	0.019	0.020	0.012	0.015	0.022	0.014	0.021	0.014	0.016
0.465	0.447	0.488	0.539	0.524	0.537	0.477	0.478	0.484	0.507	0.500	0.451	0.544	0.480	0.491	0.494	0.488	0.524	0.532	0.503
3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
46.73	45.07	49.56	54.64	52.98	54.30	48.28	48.74	49.12	51.03	50.45	45.59	55.24	48.41	49.80	50.38	49.42	53.46	53.72	51.04
57.63	58.21	55.23	55.82	55.32	56.00	54.50	58.52	58.40	58.13	58.22	58.22	57.27	56.80	58.25	62.33	62.13	60.10	58.05	56.98

Table 4 (continued)

SM42-3						SM42-4					SM33			SM33-3				
r	m	c	c	m	r	r	m	c	m	r	SM33-1			SM33-3				
266	271	272	277	280	282	296	299	304	307	312	c	c	c	c	c	m	m	r
266	271	272	277	280	282	296	299	304	307	312	365	376	391	440	441	449	451	456
0.08	0.05	0.05	0.19	0.05	0.03	0.05	0.04	0.03	0.04	0.04	0.06	0.14	0.03	0.10	0.09	0.07	0.22	0.22
0.03	0.02	0.02	0.03	0.05	0.04	0.03	0.03	0.06	0.01	0.03	0.00	0.02	0.00	0.00	0.01	0.02	0.01	0.02
23.29	22.48	22.46	23.87	21.15	19.88	22.74	22.63	22.16	22.19	24.11	23.17	26.19	24.08	22.66	24.01	24.18	23.43	23.50
44.15	44.55	44.75	44.24	45.03	43.42	44.26	44.11	44.80	44.43	43.19	44.98	43.37	45.61	46.07	46.17	46.17	46.30	44.43
20.88	20.76	20.65	20.04	20.80	21.88	20.82	20.11	20.57	20.45	19.79	18.93	15.08	15.52	15.57	15.50	15.41	15.01	19.93
0.65	0.48	0.44	0.76	0.54	1.54	0.62	0.94	0.77	0.75	0.77	0.46	0.32	0.39	0.32	0.35	0.37	0.30	0.56
10.52	11.19	11.21	11.29	11.67	11.54	11.04	11.09	11.25	11.03	11.47	11.37	13.89	13.51	14.50	13.23	13.48	14.10	10.42
99.59	99.52	99.57	100.41	99.29	98.33	99.55	98.95	99.63	98.89	99.40	98.97	99.01	99.14	99.23	99.36	99.70	99.38	99.09
0.002	0.002	0.002	0.006	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.002	0.004	0.001	0.003	0.003	0.002	0.007	0.007
0.856	0.826	0.825	0.865	0.780	0.743	0.835	0.836	0.814	0.822	0.879	0.852	0.936	0.869	0.816	0.867	0.869	0.843	0.868
0.048	0.072	0.068	0.046	0.101	0.165	0.070	0.068	0.077	0.072	0.060	0.034	0.014	0.024	0.064	0.008	0.013	0.026	0.016
0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
1.089	1.098	1.103	1.076	1.114	1.088	1.091	1.093	1.104	1.104	1.057	1.110	1.040	1.105	1.113	1.119	1.113	1.117	1.101
0.497	0.469	0.470	0.469	0.444	0.415	0.473	0.459	0.459	0.465	0.452	0.460	0.368	0.374	0.334	0.389	0.380	0.357	0.506
0.017	0.013	0.011	0.020	0.014	0.041	0.016	0.025	0.020	0.020	0.020	0.012	0.008	0.010	0.008	0.009	0.010	0.008	0.015
0.489	0.520	0.521	0.517	0.545	0.545	0.513	0.518	0.523	0.516	0.529	0.529	0.628	0.617	0.661	0.605	0.613	0.642	0.487
3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
49.63	52.56	52.59	52.44	55.10	56.78	52.01	53.03	53.26	52.62	53.92	53.49	63.05	62.29	66.41	60.83	61.71	64.23	49.03
55.98	57.07	57.20	55.42	58.82	59.44	56.63	56.66	57.56	57.32	54.58	56.56	52.63	55.97	57.70	56.33	56.16	56.99	55.92