Invited review

On the chemical markers of pyroxenite contributions in continental basalts in Eastern China: Implications for source lithology and the origin of basalts

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A B S T R A C T

Although it is widely recognized that mantle peridotite is compositionally heterogeneous, primitive mantle-like peridotite is commonly considered the potential peridotite source when identifying the source lithology of oceanic and continental basalts. Here, a simple equation that compatible with thermodynamic result (Ol (wt%) = 144.27ln((Fe + Mg + Ca + 2Na) / Si), mol ratio) is introduced to distinguish peridotitic and pyroxenitic rocks. Meanwhile, the basic assumptions, alternative interpretations and uncertainties of many of the literature markers for pyroxenite contributions in basalts are briefly summarized, and some detailed comments on these markers are presented using literature data on olivines and basalts from Eastern China. Both high-CaO (>0.1 wt%) and low-CaO (<0.1 wt%) olivines in these continental basalts are likely generated by a xenocryst diffusive re-equilibration process, suggesting that the olivine chemistry method may not be suitable for the source lithology identification of the basalts. For the Cenozoic and Mesozoic continental basalts in Eastern China, nearly all of the markers for pyroxenite sources based on whole-rock major and/or trace elements might be compromised by refertilized/metasomatized peridotite sources. These uncertainties also exist for many other oceanic and continental basalts. However, the FC3MS (FeO^T/CaO-3*MgO/SiO$_2$, all in wt%) value, combined with those of Na$_2$O + K$_2$O, Mg$^\#$, MgO and La/Yb, suggests that Cenozoic OIB-type basalts in Eastern China are mostly primary pyroxenite-derived products, and caution should be paid when interpreting the petrological and geological implications of these basalts, particularly that of the low-MgO pyroxenite-derived basalts. At the normal mantle potential temperature (~1350–1400 °C), the pyroxenite source can produce melts that explain all of the compositional characteristics of the Cenozoic basalts, suggesting that the origin temperature and pressure of the Cenozoic basalts determined by the traditional peridotite model are overestimated. For the Mesozoic basalts, compositionally diverse peridotite sources can account for their petrogenesis, but the pyroxenite source cannot be excluded. We acknowledge that the pyroxenite source may represent crustal materials (continental or oceanic crust) recycling and/or mantle metasomatism, which have important geodynamic implications, but further work is needed to determine the origin of the pyroxenite.

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1. Introduction

Identification of the source lithology of basalts plays a fundamental role in our understanding of the magmatic processes and origin of mantle-derived magmas, enabling us to gain insights into crustal material recycling and/or mantle metasomatism that contribute to mantle heterogeneity. Recently, a variety of markers have been experimentally and theoretically proposed to infer pyroxenite-derived melt contributions in both continental and oceanic basalts (Hauri, 1996; Herzberg, 2006, 2011; Lambart et al., 2013; Le Roux et al., 2010; Liu et al., 2008; Sobolev et al., 2007; Sobolev et al., 2005; Yang and Zhou, 2013), but the source lithology identification of basalts is still a debated issue because all of the markers are largely influenced by the compositional diversity of the source rocks and melting and crystallizing conditions of the basaltic magmas (Herzberg et al., 2014; Lambart et al., 2013; Matzen et al., 2013; Niu et al., 2011; Putirka et al., 2011; Yang and Zhou, 2013). Although mantle peridotite and pyroxenite from various locations around the world show large variations in bulk composition (Downes, 2007; Kogiso et al., 2004; Lambart et al., 2013; Yang and Zhou, 2013) and a wide range of compositions of peridotite and pyroxenite, such as the experimental peridotite and pyroxenite compiled in Table 1 that may be the potential source rocks of both oceanic and continental basalts, PM-like peridotite and olivine-free pyroxenite are frequently used to model the source lithology of basalts (Herzberg, 2011; Sobolev et al., 2007; Sobolev et al., 2005). Most of the samples compiled in Table 1 come from the lithosphere, but the convecting mantle, where basaltic melts can be produced, may have similar compositional characteristics through either crustal material recycling or mantle metasomatism. In providing support for the pyroxenite source, experimental melts from peridotite are typically not given sufficient attention, and many refertilized/metasomatized peridotite melts are excluded (Lambart et al., 2013; Putirka et al., 2011). However, for the classical peridotite model, many potential pyroxenite source signatures in bulk-rock major and/or trace elements of OIB-type magmas can be illustrated by refertilized/metasomatized peridotite (Davis et al., 2013; Niu et al., 2011; Putirka et al., 2011). In addition, olivines crystallized from refertilized peridotite melts exhibit many chemical similarities compared with olivine-poor or olivine-free pyroxenite melts (Herzberg et al., 2014). Consequently, the major issue of the identification of the source lithology of basalts is to distinguish refertilized/metasomatized peridotite-derived basalts from pyroxenite-derived basalts.

Intraplate continental basalts are widely distributed in Eastern China, and numerous geochemical and petrological studies have been carried out over the years (Basu et al., 1991; Chen et al., 2007; Zhi et al., 1990; Zou et al., 2000), with particularly high-quality data accumulated in recent years (Liu et al., 2015; Liu et al., 2008; Qian et al., 2015; Wang et al., 2012; Xu, 2014; Zeng et al., 2011). However, there is some debate about the source lithology of these basalts, which in turn introduces significantly different interpretations of their petrogenesis and geological implications (Huang et al., 2013; Liu et al., 2008; Niu et al., 2011; Wang et al., 2012; Xu et al., 2014; Yang and Zhou, 2013; Zhang et al., 2009). The major evidence supporting the pyroxenite source of these basalts is largely taken from those that are used to infer the source lithology of oceanic basalts (Gao et al., 2008; Hong et al., 2013; Liu et al., 2015; Liu et al., 2008; Qian et al., 2015; Wang et al., 2012; Wang et al., 2011; Xu et al., 2014; Zeng et al., 2011; Zhang et al., 2009), which may also suggest a refertilized/metasomatized peridotite source (Niu et al., 2011; Yang and Zhou, 2013; Guo et al., 2014; Guo et al., 2016). Thus, to determine the source lithology of the basalts from Eastern China, special attention should be paid to test whether refertilized/metasomatized peridotite source can explain their geochemical and mineralogical characteristics. This work aims to briefly summarize the chemical markers of the pyroxenite contribution in basalts and discuss their prerequisites, alternative interpretations and

Table 1
Compositions of typical experimental peridotites and pyroxenites that may be the source materials of basalts.

	KLB-1[a]	KR4003[b]	PM[c]	DMM[d]	HZ[e]	HPY[f]	PHN1611[g]	HK-66[h]	KG2[i]	KG1[i]	MIX1G[j]	M5–40[k]	Px-1[l]
SiO$_2$	44.48	44.9	45.00	44.71	46.62	45.2	43.7	48.02	46.22	46.97	45.60	48.53	52.67
TiO$_2$	0.16	0.16	0.20	0.13	0.08	0.71	0.25	0.22	0.57	0.78	0.90	0.52	0.64
Al$_2$O$_3$	3.59	4.26	4.45	3.98	0.65	3.54	2.75	4.88	7.69	9.75	15.20	12.37	11.26
Cr$_2$O$_3$	0.31	0.41	0.38	0.57	0.57	0.43	0.28	0.25	0.22	0.17	0.11	0.12	0.25
FeOT	8.1	8.02	8.05	8.18	4.91	8.47	10.05	9.9	9.22	9.77	7.80	9.02	7.55
MnO	0.12	0.13	0.14	0.13	0.15	0.14	0.13	0.14	–	–	0.15	0.20	0.12
MgO	39.22	37.3	37.80	38.73	46.19	37.5	37.22	32.35	28.83	23.57	16.67	16.64	18.48
CaO	3.44	3.45	3.55	3.17	0.73	3.08	3.26	2.97	6.05	7.35	11.48	10.89	7.05
Na$_2$O	0.3	0.22	0.36	0.13	0.05	0.57	0.33	0.66	1.11	1.52	1.40	1.65	1.52
K$_2$O	0.02	0.09	0.03	0.01	0.03	0.13	0.14	0.07	0.09	0.12	0.04	0.06	0.06
NiO	0.25	0.24	0.25	0.24	–	0.2	0.25	0	–	–	–	–	0.13
P$_2$O$_5$	0.03	–	0.02	0.02	–	0.04	–	0.07	–	–	0.01	–	–
Total	100.02	99.18	100.23	100.00	99.98	100.01	98.36	99.53	100.00	100.00	99.37	100.00	99.73
Ol (wt%)	66	57	60	62	67	60	65	37	41	28	11	5	−15
Mg$^\#$	89.6	89.2	89.3	89.4	94.4	88.8	86.8	85.3	84.8	81.1	79.2	76.7	81.4
Fe/Mn	67.8	61.9	59.9	63.2	32.9	60.7	77.6	71.0	–	–	52.1	45.3	63.7
Zn	–	–	55	–	–	–	81	–	–	–	–	–	–
Zn/Fe	–	–	8.79	–	–	–	10.37	–	–	–	–	–	–
La	–	–	0.69	0.192	–	–	0.89	–	–	–	–	–	–
Yb	–	–	0.49	0.365	–	–	0.33	–	–	–	–	–	–
La/Yb	–	–	1.39	0.53	–	–	2.70	–	–	–	–	–	–

[a] KLB-1, Hirose and Kushiro (1993).
[b] KR4003, Walter (1998).
[c] PM, McDonough and Sun (1995).
[d] DMM, Workman and Hart (2005).
[e] HZ, Falloon and Danyushevsky (2000).
[f] HPY, Falloon et al. (1988).
[g] PHN1611, Kushiro (1996).
[h] HK-66, Hirose and Kushiro (1993).
[i] KG2 and KG1, Kogiso et al. (1998).
[j] MIX1G, Hirschmann et al. (2003).
[k] M5–40, Lambart et al. (2009).
[l] Px-1, Sobolev et al. (2007)