Olivine in picrites from continental flood basalt provinces classified using machine learning

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ABSTRACT

Picrites, dominantly composed of highly forsteritic olivine, can serve as important constraints on primary magma composition and eruption dynamic processes in global continental flood basalt (CFB) provinces. Picrites are commonly divided into high-Ti and low-Ti groups based on whole-rock TiO2 content or Ti/Y ratio. Here, we use an artificial neural network (ANN) to classify the individual olivine in picrites from global CFB provinces according to whether their parental magma is high-Ti or low-Ti to better understand the primary origin and magmatic processes. After training the ANN on 1000 olivine major element compositions data points, the network was able to differentiate chemical patterns for high-Ti and low-Ti olivine and classify olivine into correct types with an accuracy of >95%. Moreover, we find that two types of olivine mix in some single samples from Etendeka, Emeishan, and Karoo CFB provinces. Combining the results with chemical markers of source lithology, we suggest that the two types of olivine originate from two different sources and their olivine populations mixed during the ascent. This mixing then makes the spatial and temporal variation of picrites types in some CFB provinces unclear.

Keywords: Olivine, machine learning, picrites, chemical composition, classification

INTRODUCTION

High-Ti (HT) and low-Ti (LT) types of picrites are commonly observed in continental flood basalts (CFBs) or large igneous provinces (LIPs). The classification is based on the values of TiO2 or Ti/Y of whole-rock compositions (e.g., Ewart et al. 2004; Kamenetsky et al. 2017; Peate et al. 1999; Xiao et al. 2004; Xu et al. 2001). Both types are found either in separate locations or within the same succession of a CFB. For example, in Karoo province, LT picrites (TiO2 < 1.5 wt%) are found mainly south of 26° S, whereas HT picrites predominate north of this latitude (Galerne et al. 2008). The different locations may indicate the two types were produced from different magmatic sources (e.g., Heinonen et al. 2013; Heinonen and Luttinen 2008; Howarth and Harris 2017; Kamenetsky et al. 2012). On the other hand, in Emeishan province, the two types are found within the Binchuan succession (e.g., Cheng et al. 2014; Xu et al. 2001). Why the two types of picrites occur in many LIPs is unclear. Neither is it clear why the two types occur both separately and together. Since picrites are predominantly composed of highly forsteritic olivine, HT samples possibly consist of HT olivine, and LT samples consist of LT olivine. In addition to HT and LT samples, some picrites have intermediate Ti/Y value (IT), and do not show clear characteristics of either HT or LT in Emeishan LIP (Kamenetsky et al. 2012). Existence of IT samples may indicate the mixing of multiple olivine populations, which should be confirmed because the composition of picrite is usually used to constrain the source composition (e.g., Zhang et al. 2006). Source compositions cannot be constrained correctly from multiple olivine populations.

To address these issues, we need to analyze the chemical patterns of olivine in picrites. For this study, we have compiled thousands of compositions of olivines from published picrites samples and built an artificial neural network (ANN) to investigate the chemical characteristics of olivine from HT and LT picrites. Furthermore, we determined the links between olivine populations and their sources and answered whether olivine populations mixed during magmatic processes.

METHODS

Database of olivine compositions in picrites

We have collected thousands of major elements data points of olivine as well as their whole-rock compositions of picrites from six CFBs (Emeishan LIP, Etendeka province, Ethiopian CFB, Karoo LIP, North Atlantic province, and Siberia CFB) from the open-access and comprehensive global petrological database GEOROC (http://georoc.mpch-mainz.gwdg.de/georoc/). These CFB provinces are located in different parts of the Earth and have been well studied (Fig. 1). Within the data, Ti/Y values of picrites range from 250 to 1400 (Fig. 2). The picrites from the Ethiopian province have the highest Ti/Y values of 1400, while the maximal values of other CFBs are around 800 (Fig. 2). Although Xu et al. (2001) suggested that the Ti/Y value boundary between HT and LT is 500 for the Emeishan LIP, the boundaries for different provinces may vary between 350 and 600 based on the gaps in data in Figure 2. Thus, we assumed that samples with Ti/Y of more than 600 were HT end-members, samples with Ti/Y of <350 were LT end-members, and samples with Ti/Y from 350 to 600 were the intermediate Ti group (IT).

We determined the quality of olivine data set, which comprised 2898 major element compositions of olivine from picritic samples of CFBs (Online Materials1 Table OM1), by calculating the cardinality, minimum, mean, median, maximum, and standard deviation of each element’s concentration (Table 1). Note, that in this study we assume all the collected data could represent the true composition of whole olivine by measuring the composition of the core of olivine without the effect of diffusion (e.g., Cheng et al. 2020; Costa 2021; Costa et al. 2020) and the random cut effect in thin sections (e.g., Cheng et al. 2017; Cheng and Costa 2019). The cardinality measures the number of distinct values. The cardinalities of TiO2 were much lower than 1000, and the minimum value and mean value were lower

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