TANG Qingyan, ZHANG Mingjie, WANG Qili, WANG Yang and LI Jianping, 2014. The Ore-forming Conditions of the Zhubu Magmatic Ni-Cu-PGE Deposit, Emeishan Large Igneous Province, SW China: Constraints from Hf-Sr-Nd -C Isotopic Compositions and Volatile Chemical Compositions. *Acta Geologica Sinica* (English Edition), 88(supp. 2): 316-317.

The Ore-forming Conditions of the Zhubu Magmatic Ni-Cu-PGE Deposit, Emeishan Large Igneous Province, SW China: Constraints from Hf-Sr-Nd-C Isotopic Compositions and Volatile Chemical Compositions

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1 Introduction

The Zhubu magmatic Ni-Cu-PGE deposit is hosted in a small mafic-ultramafic intrusion which belongs to the Permian Emeishan large igneous province (ELIP) in SW China and northern Vietnam. Most of the mafic-ultramafic intrusions in the ELIP host world-class magmatic Fe-Ti-V oxide deposits; only a few of them host magmatic Ni-Cu-PGE sulfide deposits including the Zhubu deposit. A better understanding of fundamental controls on sulfide mineralization in the Zhubu intrusion is important in mineral exploration.

2 Geological Background

The Zhubu intrusion consists of a layered sequence with sub-horizontal modal layering wrapped by a sub-vertical marginal zone (Tang et al., 2013). The layered sequence makes up >90 vol.% of the current intrusion. In the layered sequence, ultramafic rocks (lherzolite, olivine websterite) are overlain by mafic rocks (gabbro, gabbrodiorite) with gradational contacts between them.

3 Samples and Analytical Methods

The samples used in this study were collected from outcrops and the walls of an open pit in the western part of the intrusion. Twelve samples from the marginal zone in the western part of the intrusion are lherzolite and olivine websterite. Three samples from the marginal zone in the northern part of the intrusion are lherzolite, gabbro and gabbrodiorite. Ten samples from the layered sequence are olivine websterite, gabbro and gabbrodiorite. The petrography and petrochemical features were described in details by Tang et al. (2013). A total of 11 samples of mineral and matrix separates were prepared from hand-specimen.

Zircon U–Pb isotope analysis was performed using a SHRIMP-II machine and Neptunemulti-collector ICP-MS equipped with a New Wave UP 213 laser-ablation sampling system. Zircon Lu-Hf isotopes were determined *in situ* using LA-MC-ICP-MS. Rb-Sr and Sm-Nd isotopic compositions were analyzed for olivine, pyroxene mineral separates using TIMS.

The volatiles released from olivine and pyroxene separates from the Zhubu intrusion by vacuum stepwise-heating (100°C per step) at three different temperature intervals of 200–400°C, 400–900°C and 900–1200°C were determined for chemical compositions and C isotopes by mass spectrometry and GC-C-Mass spectrometry, respectively. The chemical compositions and abundances of volatiles in the samples were determined using a MAT-271 mass spectrometer connected to a vacuum stepwise heating system. Carbon isotopes of CO_2 and CH_4 is the reference standard), were analyzed by a Gaschromatography-Combustion-Mass spectrometer system using a stepwise-heating extraction procedure.

4 Results and Discussion

Our new LA-MC-ICP-MS zircon U-Pb isotopic analyses gives a mean age of 263.2 ± 5.6 Ma for the intrusion, which is similar to the SHRIMP zircon U-Pb age of 261±2 Ma for the intrusion reported previously by Zhou et al. (2008). The ε_{Hf} (t = 263 Ma) values of the co-magmatic zircon crystals from the Zhubu intrusion vary from -3.05 to +3.61, which are slightly lower than those for the coeval Fe-Ti-V oxide ore-bearing mafic-ultramafic

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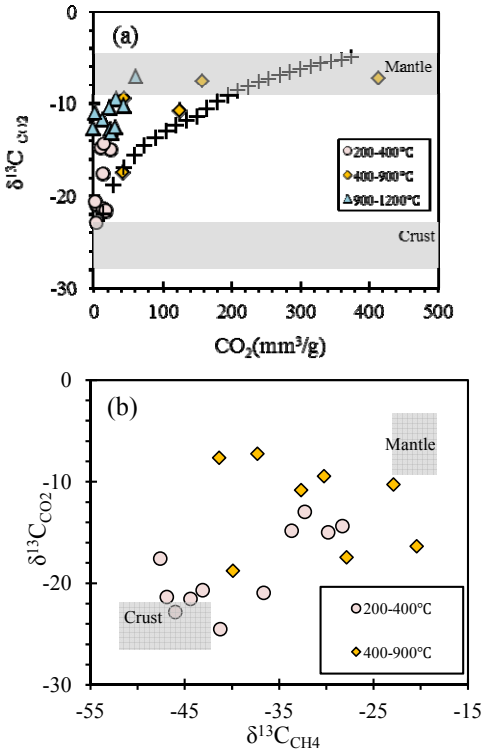

Fig. 1. Plots of $\delta^{13}C_{CO2}$ versus CO_2 contents (a) and $\delta^{13}C_{CO2}$ versus $\delta^{13}C_{CH4}$ (b) from the Zhubu mafic rocks

intrusions and basaltic andesite in the ELIP.

The $(^{87}Sr/^{86}Sr)_i$ and ε_{Nd} (t = 263 Ma) values of pyroxene separates from the Zhubu mafic-ultramafic rocks vary from 0.705882 to 0.708912 and from –2.8 to 0.7, respectively. These values are significantly lower and slightly higher than those for whole-rock samples from the intrusion (Tang et al., 2013; Zhou et al., 2008), respectively, suggesting that pyroxene is less susceptible to hydrothermal alteration than bulk rocks, especially for Sr isotopes. The $(^{87}Sr/^{86}Sr)_i$ and ε_{Nd} values of pyroxene separates from the Zhubu intrusion are similar to those of whole-rock samples from other coeval Ni-Cu-PGE sulfide ore-bearing intrusions in the ELIP. The ε_{Nd} and ε_{Hf} values of the Zhubu intrusion are slightly lower than those for the coeval Fe-Ti-V oxide ore-bearing intrusions (Zhong et al., 2011). The observed isotope variations between these two types of mafic-ultramafic intrusions in the ELIP are consistent with source mantle heterogeneity (Zhou et al., 2008) or different crustal contamination.

The volatiles released at the intermediate and high temperature intervals are mainly composed of H_2O, with minor H_2, CO_2, H_2S, CO and SO_2, and have $\delta^{13}C_{CO2}$ values varying from -17.5 ‰ to -7.1 ‰ and $\delta^{13}C_{CH4}$values varying from -41.3‰ to -20.4‰. These values are between the mantle and crustal values (Fig.1). A plausible interpretation is that the volatiles are derived from decrepitation of secondary fluid (H_2O-dominant) inclusions and primary CO_2 and CH_4 inclusions at variable ratios. In contrast, the volatiles released at the low temperature interval are also dominated by H_2O, but with minor C_2H_6, N_2 and CO_2, and have lower $\delta^{13}C_{CO2}$ values (-24.52 ‰ to -12.97 ‰) and lower $\delta^{13}C_{CH4}$values (-48.81 ‰ to -28.28 ‰), indicating more dominant contributions from secondary fluid inclusions.

5 Summary

The ore-forming magmatic volatiles are dominated by H_2O with minor CO_2 and H_2, indicating a weak reduced, volatile rich environment.

The Hf-Sr-Nd-C isotopes of the Zhubu intrusion indicated that the primary magma was derived from depleted mantle and may have experienced nearly 10-15% contamination if the contaminant was the average crust.

Acknowledgements

This study was financially supported by the NSF of China (41372095, 41072056 and 40772058), State Key Lab of Ore Deposit Geochemistry (China (201110, 201205), Gansu Key Laboratory of Western China's Mineral Resources (WCRMGS-2014-04), and China Geological Survey (12120114044401).

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