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The transition of the magma plumbing system of Tianchi shield-forming basalts, Changbaishan Volcanic Field, NE China: Constraints from dynamic Fe-Mg diffusion modeling in olivine

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Abstract

The depths of crustal reservoirs within volcanic systems may experience transitions over time. Here, we report the crystal and bulk rock compositions of the shield-forming basaltic lavas of the Tianchi composite volcano in the intraplate Changbaishan Volcanic Field, NE China, to constrain crustal magmatic evolution with time. We investigated samples covering the entire basaltic stratigraphic sequence, consisting of the Toudao (TD), Baishan (BS), and Laofangzixiaoshan (LFZ) units from bottom to top, respectively. The core compositions of olivine macrocrysts vary among the three units, i.e., the TD and BS olivine phenocrysts can be divided into two populations: a high-Fo population ($\sim Fo_{76–80}$) and a low-Fo population ($\sim Fo_{72–74}$). The LFZ unit only exhibits a high-Fo population ($\sim Fo_{77–80}$). Phase equilibria modeling using rhyolite-MELTS suggests that the high-Fo populations were stored at depths of ~20 km for the TD and BS units and ~15 km for the LFZ unit. The low-Fo populations crystallized at shallow depths, i.e., 15 km for the TD unit and 13 km for the BS unit.

We employ dynamic Fe-Mg interdiffusion modeling with constantly adapting boundary conditions in zoned olivine macrocrysts to constrain the magmatic environments and timescales during the pre- and post-eruption phases, enabling us to clarify the magmatic histories recorded by the two olivine populations. The dynamic Fe-Mg interdiffusion modeling considers the variable boundary conditions caused by crystal growth and composition variations of melts during magma cooling. Calculated results suggest that the high-Fo populations from the TD and BS units recorded prolonged timescales ranging from six months to more than two years with lower cooling rates and slower crystal growth rates. These characteristics reflect a relatively hot and slow-cooling magmatic environment, and the modeled timescales correspond to the sum of the time, including shallow storage, magma ascent, and further cooling within the lava flows. Conversely, the high-Fo population from the LFZ unit and the low-Fo populations from the TD and BS units record shorter timescales (<140 days) with higher cooling rates and faster crystal growth rates. These results indicate relatively cold and highly undercooled magmatic environments; hence, the timescales record magma ascent in the conduits and further cooling during lava emplacement. Our study demonstrates that the Tianchi basaltic plumbing system experienced a structural transition over time. In detail, the TD and BS magmas experienced multi-stage stalling and ascent, first accumulating in deep reservoirs and then ascending to shallow reservoirs for storage before the eruption. The LFZ magmas accumulated in a mid-crustal reservoir, followed by a direct ascent to the surface without additional residence.

Keywords: Changbaishan, volcano, olivine, diffusion, magma plumbing system