Magmatic volatiles and platinum-group element mineralization in the Stillwater layered intrusion, U.S.A.

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Abstract

The activity of volatile-rich fluids may be important in the evolution of basaltic magmatic systems and associated precious metal ore formation. There is evidence for Cl-rich fluids within the Stillwater Complex (Montana, U.S.A.), which have been linked to platinum and palladium mineralization in the economically important Johns-Manville (J-M) Reef ore body. We present the first data set for heavy halogens (Cl, Br, and I) and natural noble gas isotopes in bulk rock and mineral separates from the Peridotite Zone and the Olivine-Bearing Zone I of the Stillwater Complex, including samples from the J-M Reef and G Chromitite bodies. Our data reveal concentration of 4 to 13 500 ppm for Cl, 26 ppb to 360 ppm for Br, and <1 ppb to 9 ppm I over the whole sample set. Cl, Br, and I correlate well with each other implying a shared process and/or distribution in mineral species. Br/Cl and I/Cl ratios span a range from 0.3 to 35 × 10⁻³ and 5 to 900 × 10⁻⁶ by weight, respectively, encompassing MORB-like to more enriched compositions, particularly for Br/Cl. High-Br/Cl ratios compared to MORB in some Stillwater samples suggest fractionation of halogens during the exsolution of a volatile-rich fluid to explain the most Br-enriched samples. More generally, the presence of minerals such as scapolite, hornblende, and apatite in the most halogen-enriched samples suggests that the halogen-bearing fluids were derived from the cooling of the intrusion rather than late-stage (low-temperature) metamorphism. The combined halogen abundance and noble gas isotope data set imply that crustal contamination may have played a limited role in the crystallization of pegmatoids and the G Chromitite but is not required to account for the halogen budget of the J-M Reef. High-halogen contents in the sulfide-bearing J-M Reef and associated lithologies are consistent with the influence of fluid-related activity during platinum-group element (PGE)-Reef formation, lending weight to the hydromagmatic model for mineralization in the Stillwater intrusion. Our new data also imply chalcophile tendencies of Br and I over Cl in sulfides in natural systems, hinting at the importance of sulfide liquid interaction with halogen-rich fluids in the formation of sulfide-hosted precious metal ore deposits.

Keywords: Halogens, platinum-group elements, Stillwater intrusion, metasomatism, J-M Reef; Experimental Halogens in Honor of James Webster

Introduction

Layered mafic-ultramafic intrusions represent the solidified remnants of basaltic magmatic systems (Wager and Brown 1968; Parsons 1987; O’Driscoll and Van Tongeren 2017). These bodies are therefore important repositories of information for the geochemical and petrological processes that operate during the solidification of magma in the Earth’s crust. An abundance of evidence in layered intrusions, including within the ~2.06 Ga Bushveld Complex (South Africa; Scoates and Wall 2015) and the ~2.71 Ga Stillwater Complex (Montana, U.S.A.; Wall et al. 2018); suggests that postcumulus processes such as recrystallization and metasomatism of the partly-to-completely solidified crystal mush pile by late-stage volatile-rich fluids occurred (e.g., Stumpfl 1974; Schiffries 1982; Stumpel and Rucklidge 1982; Boudreau and McCallum 1986; Boudreau et al. 1986; Boudreau 1999; Meurer et al. 1999; Willmore et al. 2000; McBirney 2002; Hanley et al. 2008; Schannor et al. 2018; Su et al. 2020). The postcumulus circulation of volatile-bearing (e.g., halogen, F, Cl, Br, I) fluids may lead to the alteration of primary igneous assemblages, the formation of pegmatoid bodies, and the complexing and redistribution of base- and precious-metal species (Schiffries 1982; Boudreau 1999, 2016; Meurer et al. 1999; Willmore et al. 2000).

Several layered intrusions host economic abundances of the precious metals, such as the platinum-group elements (Os, Ir, Ru, Rh, Pt, and Pd; PGE). The PGE typically occur in stratiform (but not stratabound) layers referred to as “reefs,” and a handful of such ore bodies dominate global supply of Pt, Pd, and Rh (e.g., the reefs of the Bushveld Complex account for ~75%, ~52%, and ~82% of worldwide production of these metals, respectively; Mungall and Naldrett 2008). The petrogenesis of PGE-bearing reefs has been a topic of substantial debate, traditionally dominated by two main opposing schools of thought—either miner-