FLUIDS IN THE CRUST

Chemical interactions between a sedimentary diapir and surrounding magma: Evidence from the Phepane Dome and Bushveld Complex, South Africa†

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ABSTRACT

The Phepane Dome is a circular outcrop of metasedimentary rock within the Eastern Lobe of the Bushveld Complex hypothesized to have formed as a diapir, when underlying wallrock rose into the overlying magma body. Interactions between the metasedimentary rock of the Phepane Dome and the magma of the Bushveld Complex were investigated through measurements of oxygen and lithium isotopic compositions, determination of mineral modes and major-element mineral compositions, cathodoluminescence imaging, and dihedral angle analysis. Evidence from cathodoluminescence imaging and dihedral angle analysis suggest that heat transfer during diapirism caused partial melting and complete recrystallization of the Phepane Dome metasedimentary rock. Oxygen isotope analysis of samples from traverses spanning the contact between metasedimentary and igneous rocks demonstrates that relatively minimal exchange of oxygen (over distance ~4 m) occurred across the contact between the Phepane Dome and the surrounding Bushveld magma. The lithium concentrations and isotopic compositions of metasedimentary rock are significantly different from the associated igneous rocks. Lithium isotope analysis of samples from traverses across the contact demonstrates exchange of Li over somewhat greater distances (~60 m) than oxygen, consistent with evidence that suggests a higher diffusivity of Li than most major elements. Models of oxygen diffusion through intergranular melt and aqueous fluid are used to place maximum constraints on the duration of diffusive exchange across the contact, resulting in estimates ranging from 5 kyr to 5 Myr. These values are consistent with previous estimates of the duration of crystallization of the Bushveld Complex and Phepane diapir development.

Keywords: Lithium, lithium isotopes, oxygen isotopes, partial melt, aqueous fluid, diffusion, metamorphic petrology, igneous petrology

INTRODUCTION

The largest layered mafic intrusion in the world, the Bushveld Complex of South Africa, formed as mafic to ultramafic magma intruded sedimentary rocks of the Transvaal Supergroup (~2054 Ma (Walraven et al. 1990; Buick et al. 2001)) (Fig. 1a). Metasedimentary domes found within the mafic rock of the Eastern Lobe of the Bushveld Complex are interpreted to have formed as diapirs of partially melted, sedimentary footwall rock that rose through the denser mafic magma (Uken and Watkeys 1997) (Fig. 1b). Evidence for this sedimentary diapirism comes from gravity and structural data (Molyneux and Klinkert 1978). The Phepane Dome crops out as one of these domal structures of metasedimentary rock surrounded by Bushveld Complex rock in the northern Eastern Lobe and shows both structural and mineralogic evidence for a diapiric origin (Johnson et al. 2004).

Gerya et al. (2003, 2004) described the formation of the Phepane Dome as “cold diapirism,” since cooler, less dense sedimentary rock rose into the hotter, more dense Bushveld Complex crystallizing magma. Similar “cold diapirism” is hypothesized to occur in subduction zones (Hall and Kincaid 2001; Gerya and Yuen 2003). To better understand this cold diapirism within the Bushveld Complex magma, studies have modeled the growth of the Phepane diapir (Gerya et al. 2004) and documented the metamorphic reactions that occurred in the sedimentary rock at the center of the Phepane Dome (Johnson et al. 2004). However, there is limited study of these thermally dynamic settings where chemical buoyancy plays such an important role. This study investigates chemical interaction between the Bushveld Complex magma and the sedimentary rock that rose as the Phepane diapir using Li and O isotopes as chemical tracers.

The properties of Li, a fluid-mobile element with a ~17% mass difference between the two stable isotopes (~Li and "Li), make it a useful tracer for settings where fluids and rock interact. Recent studies have reported Li isotopic compositions and concentrations in contact metamorphic settings (e.g., Teng et al. 2006a; Marks et al. 2007), and O isotope data has been used in previous studies of intrusion-wallrock contacts (e.g., Shieh and Taylor 1969; Cartwright and Valley 1991; Park et al. 1999; Baumgartner and Valley 2001). During contact metamorphism, the juxtaposition of two chemically disparate rock types at relatively high temperatures can lead to chemical or isotopic exchange across the contact. Such mass transfer between the two reservoirs is facilitated by diffusion due to gradients in chemical potential. The extent of the transfer relies on several physical properties of the exchange media as well as on the length of time the two reservoirs are in contact at high temperatures. Therefore,