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(^{210}Pb/^{226}Ra) variations during the 1994–2001 intracaldera volcanism at Rabaul Caldera

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ABSTRACT

Determining the timing and source of gas transfer during intermittent intracaldera volcanism can aid in our understanding of degassing in these large systems. Using (^{210}Pb/^{226}Ra) ratios, (parentheses denote activity ratios) as a time-sensitive tracer, injections of ^{222}Rn and the subsequent time scales of gas accumulation and loss can be determined. Variations in (^{210}Pb/^{226}Ra) have been measured for 15 volcanic products erupted at Rabaul Caldera over the period 1994 to 2001. In addition, one basaltic enclave from the 1937 eruption was also analyzed. Water and carbon dioxide contents determined from olivine hosted melt inclusions erupted in 1997 are <1% and suggest extensive shallow-level degassing. Both ^{210}Pb excesses and deficits are found in andesites and dacites, whereas the basaltic enclave displays an (^{210}Pb/^{226}Ra)$_0$ ratio of 7. Between 1994 and 1997 three samples with (^{210}Pb/^{226}Ra) deficits were erupted which indicate open system gas loss since 1992 and 1994. No correlation exists between (^{210}Pb/^{226}Ra) and lava chemistry, eruptive style or date. ^{210}Pb excesses are more common than deficits in Rabaul samples but cannot be explained by plagioclase feldspar accumulation, Pb sublimate accumulation or differentiation. Instead, a model of intra-magma ^{222}Rn transfer can produce ^{210}Pb excesses of the appropriate magnitude if gas transfer occurs over 1–5 years from an underlying body of magma that is 2–10 times larger than the volume of erupted material and that is consistent with geophysical estimates. Although intermittent gas transfer events can be inferred by the development of ^{210}Pb excess, there is no evidence at Rabaul for a direct link between eruptive style, gas flux and (^{210}Pb/^{226}Ra).

1. Introduction

It has long been recognized that injections of fresh mafic magma into a magma chamber can trigger a volcanic eruption (Sparks et al., 1977). Evidence of such injections includes mafic enclaves (Browne et al., 2006), banded pumice (Lautze and Houghton, 2005), minerals in disequilibrium with their host rock (Nakagawa et al., 2002) and coeval eruption of basalt and dacite (Eichelberger and Izbekov, 2000). However, the timing of injections and their impact on the resident magma is less well constrained. For example, some volcanoes erupt with little precursor activity while others can show signs of restlessness for up to a decade prior to eruption.

Theoretical studies of magma mixing suggest that physical mixing will be suppressed if large rheological or thermal differences exist (Sparks and Marshall, 1986). However, even though mass transfer may not occur, heat and volatile transfer across the magma interface are possible. Volatile refers to the gaseous species H_2O, CO_2 and SO_2, which can become oversaturated in the melt at low pressures and form gas bubbles. Accumulated volatiles may originate from the resident magma and/or they can be introduced by fresh batches of magma. Crystallization of the resident magma causes increases in the concentration of volatiles in the residual melt, a process referred to as second boiling. In addition, injection of new undegassed magmas can introduce volatiles, causing oversaturation, further degassing, and the nucleation of bubbles that ascend into the overlying magma. Vesicular mafic enclaves may attest to such volatile and mass transfer between two magmas (Thomas and Tait, 1997). Folch and Marti (1998) modeled the influence of volatile saturation on eruption triggering and concluded that only the introduction of volatile-saturated magmas can create large enough overpressures to trigger an eruption.

One of the limitations of volatile studies is that the source and timing of exsolution is difficult to constrain. Some volcanoes display "excess S" whereby more SO_2 is emitted into the atmosphere than is in equilibrium with the magma (Wallace, 2001). Other volcanoes can degas large volumes of H_2O and CO_2 for decades without erupting. To further our understanding of volatile sources and eruptive triggering a time sensitive measure needs to be integrated. Recently, the U-series

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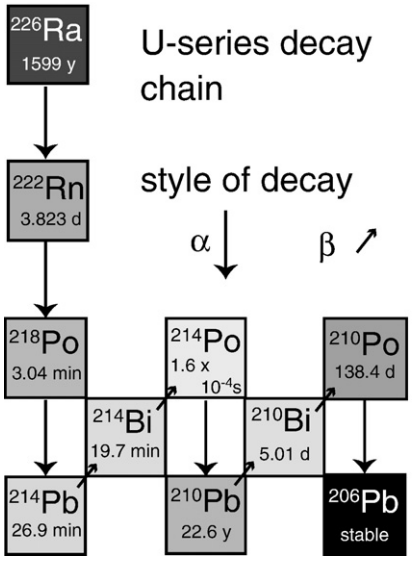

Fig. 1. U-series decay chain (Bourdon et al., 2003).

nuclide pair ^{210}Pb–^{226}Ra has been applied to degassing problems because intermediary ^{222}Rn is volatile. This isotopic pair not only can be used to constrain the time scales of gas loss, but can also be used to track inputs of new undegassed magma.

The aim of this study is to use volatile measurements and ^{210}Pb–^{226}Ra disequilibria to examine gas transfer during intracaldera volcanism at Rabaul Caldera. This is the first study to assess the timing of gas transfer in an active caldera and builds upon previous work that has constrained the processes and time scales of differentiation (Cunningham et al., 2009).

2. Background

2.1. U-series Isotopes

^{238}U decays into a number of radioactive intermediate nuclides until stable ^{206}Pb is formed (Fig. 1). While many studies have assessed the time scales of magmatic processes using ^{238}U–^{230}Th–^{226}Ra (e.g. Condomines et al., 2003; Reid, 2003 and references therein), the application of ^{210}Pb to degassing studies is relatively new. Disequilibria between U-series nuclide ^{210}Pb (half-life 22 years) and its progenitor ^{226}Ra (half-life 1600 years) provides a unique means to

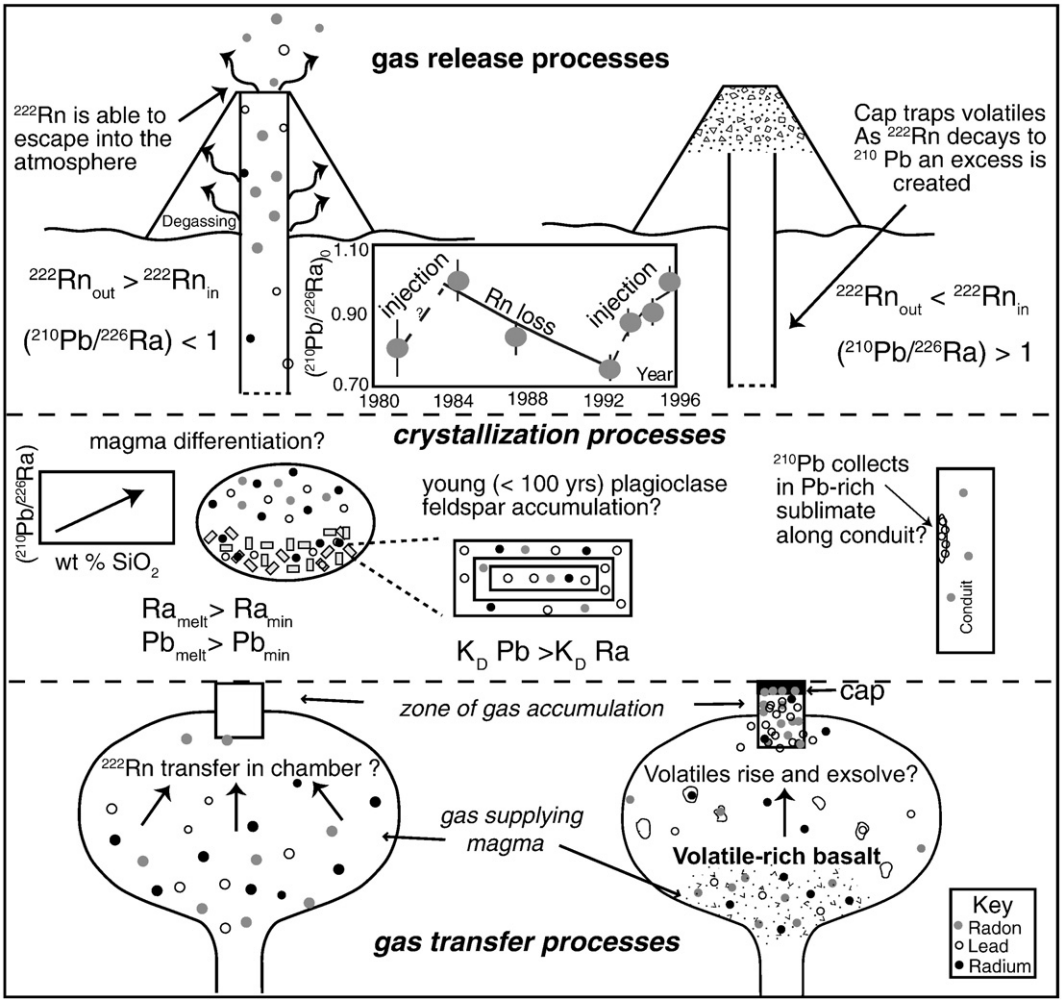

Fig. 2. Cartoon depicting the concepts presented in this paper. Previous studies identify three distinctive ways in which (^{210}Pb/^{226}Ra) disequilibria can be developed. (Top) Gas release occurs from the open conduit. As a result of gas escape ^{222}Rn will be lost from the volcanic system resulting in (^{210}Pb/^{226}Ra) <1. Gas collection will trap ^{222}Rn, which will decay into ^{210}Pb after 20 days (5 half-lives) resulting in (^{210}Pb/^{226}Ra) >1. (Middle) ^{210}Pb can be collected by fractionation processes: internal differentiation, plagioclase feldspar accumulation or contamination by ^{210}Pb-rich sublimates. Since both Pb and Ra are incompatible in most mineral phases, differentiation could concentrate these elements in the melt relative to crystals. However, Pb is slightly more compatible in plagioclase, so recent crystallization can create ^{210}Pb excesses. Also Pb and Ra are not volatile, unlike Rn, so can collect in sublimate phases in the conduit. (Bottom) In the magma chamber ^{222}Rn may either be collected from a much larger degassing body or introduced by a new undegassed magma. Note that the examples for ^{222}Rn collection in the chamber are not coupled to the mechanisms of gas accumulation or loss in the upper conduit.