News feature

Fast and furious: crustal CO_2 release at Merapi volcano, Indonesia

New experimental results show that when magma interacts with carbonate-rich crustal rock, such as limestone, it rapidly liberates crustal CO_2, with potentially devastating repercussions for explosive volcanic behaviour.

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Volcanoes located over carbonate-rich sedimentary rocks often emit large volumes of CO_2 and have strong records of explosive activity. Examples include Vesuvius and the Colli Albani volcanic field in Italy; Popocatepetl in Mexico; and Merapi in Indonesia, all of which display petrological and/or gas-chemical evidence for magma-carbonate interaction. Merapi is one of the most active volcanoes in Java (Fig. 1), and represents a serious hazard by being located less than 30 km from Yogyakarta, the largest city in Central Java with a population of about 3.5 million. In this article, we discuss the outcome of recently-published experimental results demonstrating that CO_2 can be released through a magma-carbonate interaction more rapidly than had been previously expected. As carbonate rocks are considered to be an important source of the volcanic CO_2 at Merapi, and because they are also a potential influence on eruption dynamics, understanding the timescales of crustal CO_2 degassing is important in improving eruption forecasting at carbonate-hosted volcanoes.

Recent work using crystal isotope stratigraphy has confirmed carbonate assimilation events at Merapi (see Further Reading). To replicate this process experimentally, we allowed Merapi basaltic-andesite and limestone to interact at magmatic pressure and temperature for varying durations (up to 300 seconds) revealing a reaction series of carbonate as-

Fig. 1. A. Merapi volcano, Central Java, before the 2006 eruption with Kali Adem village in the foreground. **B.** The same view as in (**A**) showing destruction at Kali Adem in the wake of the eruption. **C.** Same view as before showing Kali Adem in September 2008. The pavilion recurring in each panel is indicated with an arrow.

similation through time—thereby opening a window into the rates and the processes involved. We carried out two experimental series in parallel, one using anhydrous and the other using hydrous (H_2O = 2.5 wt%) basaltic andesite. Our results show that within 150 seconds for anhydrous experiments, and only 90 seconds for hydrated experiments, assimilation is accompanied by vigorous CO_2 bubble growth and coalescence (Fig. 2).

Moreover, for magmatic plumbing systems located at shallower depths than investigated in our study (i.e. less than 10–15 km), we expect CO_2 bubble formation and growth to be even more rapid and vigorous than in our experiments, because CO_2 becomes less soluble in silicate melts with decreasing pressure. Our experimentally-constructed reaction series probably represents an end-member for the timescale of CO_2 gas production, meaning that in natural systems CO_2 production will occur at similar or even higher rates. It is conceivable that carbonate assimilation in nature will produce large outbursts of CO_2 on a timescale of just hours to days, as observed at Popocatepetl volcano.

At 'Popo', CO_2 outbursts amounting to 32 000 t/day have been documented during eruptive periods. This amount of CO_2 can be liberated by assimilating a limestone cube of about 80 m side length over just two weeks. As the rate of magma-carbonate interaction is dependent on the availability of reaction surfaces, processes such as thermal expansion (cracking) of wall rocks and xenoliths, dyke and fresh magma injections, and volcano-tectonic earthquakes will both initiate and accelerate this process. This is exemplified by the major Yogyakarta earthquake (M = 6.4) on 26 May 2006, which coincided with ongoing eruptive activity at Merapi. In the 16 days following the earthquake, dome growth and collapse activity increased by up to a factor of three. It is likely that associated stress changes in the upper crust fractured the limestone units underlying Merapi, allowing release of trapped CO_2 and possibly renewed magma-carbonate interaction on newly generated reaction surfaces. As our experiments demonstrate, this process would have rapidly increased the CO_2 pressure in the magma plumbing system, and, in turn, promoted increased eruptive activity.

Our experiments suggest that CO_2 bubble growth formed by limestone assimilation into magma is fast. The sudden formation of CO_2 bubbles, followed by rapid bubble expansion, intensifies markedly the explosivity of magma and may change a volcano's eruptive style with potentially very little forewarning. This has serious implications for hazard mitigation at densely populated, carbonate-hosted volcanoes (e.g. Popocatepetl, Vesuvius, Merapi), where emergency response teams must be prepared for the erratic nature of events unfolding during CO_2-driven volcanic crises.

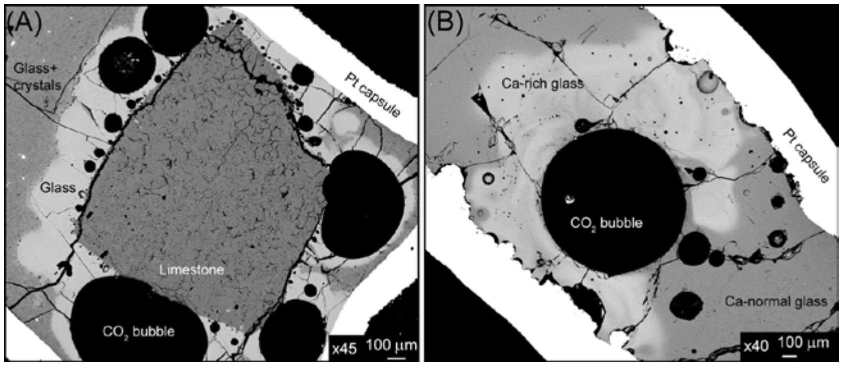

Fig. 2. Scanning electron microscopy images of limestone assimilation experiments. **A.** Experiment held for 150 s at 1200 °C and 0.5 GPa using anhydrous starting material. Large CO_2 bubbles can be seen emerging from the limestone grain which is surrounded by a corona of Ca-contaminated glass (bright grey). **B.** Experiment held for 90 s at 1200 °C and 0.5 GPa using hydrous starting material. A large, coalesced CO_2 bubble is surrounded by Ca-contaminated glass. The limestone has already been completely assimilated, showing that the reaction proceeds faster under hydrous conditions that are typical for subduction zone volcanoes such as Merapi.

Suggestions for further reading:

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