Elevated crustal CO_2 liberation at Merapi volcano: linking rock-, mineral- and gas-geochemistry

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Indonesia's Merapi volcano is one of the most active and dangerous on the planet, characterized by long periods of dome growth and intermittent explosive pyroclastic events. Merapi currently degasses continuously through high-T fumaroles (>200°C), and has recently erupted mainly crystal-rich basaltic-andesite that contains a large range of igneous and calc-silicate crustal inclusions. To evaluate mechanisms that trigger explosive eruptions, we sampled lavas, inclusions (xenoliths), and gas from active fumaroles. We also experimentally established a time-integrated reaction series of crustal assimilation at Merapi under magmatic conditions.

Merapi lava contains abundant, complexly zoned plagioclase crystals that show variations in anorthite (An) content between 40 and 95 mol% across resorption surfaces. A negative correlation between An content and other indicators of magmatic fractionation, such as MgO and FeO, has been observed. Moreover, *in-situ* Sr isotope analysis of discrete zones in plagioclase yields $^{87}Sr/^{86}Sr$ values that notably exceed those of the host lavas. Zones with the highest An content tend to also show the highest radiogenic Sr values, and, by contrast, low MgO, consistent with a Ca-rich, MgO-poor crustal contaminant. Abundant metamorphosed crustal limestone xenoliths contain compositionally identical feldspar to the lavas (up to An_{95}), demonstrating that magma-crust interaction is a significant process at Merapi.

Carbon isotope ratios of fumarole CO_2 sampled during quiet periods form a baseline of $\delta^{13}C_{2001\text{-}2006} = -4.1‰$. The notable exceptions are the 2006 values, sampled during the eruption and after the 6.4 magnitude Yogyakarta earthquake, which show elevated $\delta^{13}C$ values up to -2.4‰. Notably, the rise in $\delta^{13}C$ values coincided with an increase in eruptive intensity and volcano seismicity by a factor of 3 to 5 for several weeks after the earthquake. This is consistent with a late-stage, crustal volatile component added to purely mantle and slab-derived volatile sources, arguing for extensive and ongoing magma-crust interaction beneath the volcano, especially during eruptive and/or seismic events.

High P-T experiments show that interaction between Merapi magma and limestone can rapidly liberate crustal CO_2 on a timescale of only seconds to minutes in our experiments [1]. We therefore expect vigorous CO_2 bubble nucleation and growth on a scale of perhaps hours to days in nature. Late volatile input could therefore accelerate or trigger explosive eruptions independently of magmatic recharge and fractionation by sudden over-pressurization of the upper parts of the magma system. Such an event would provide shallow seismic warning signals only and these would be temporally very close to an erratic, CO_2-driven, eruption crisis.

[1] Deegan, F. M., Troll, V. R., Freda, C., Misiti, V., Chadwick, J.P., McLeod, C.L., Davidson, J.P., (2010), *J. Petrol.*, **51**, 1027-1051.

Paleo-environmental characterization of the Pelusiac branch of the Nile (Egypt)

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The paleo-Pelusiac branch of the Nile delta once housed Avaris, the capital city of the Hyksos kings during the 2nd millenia BC. The now defunct Pelusiac branch also was one of the seven largest diffluents of the Nile and therefore offers the opportunity to investigate paleo-environmental changes in the delta according to hydrological fluctuations and anthropogenic activities.

The Nile has three main affluents that connect in Sudan, the White Nile, the Blue Nile and the Atbara river, more than 2.500km south of the apex of the delta. These three rivers drain much dissimilar geological basins, from the plutonic rocks of the White Nile to the effusive rocks of the Blue Nile. The heavy metals load carried by the Nile reflects this diversity along with dust deposition from Saharan plumes and local discharge from anthropogenic activities. Lead (Pb) and its stable isotopes are known to efficiently trace the geological diversity of sediment particles and to discriminate anthropogenic sources leached into natural reservoirs thanks to the specific imprint of metallic ores [1]. Here we propose to use these isotopes measured from cores collected in the Pelusiac branch to resolve (1) changes in sediment source dynamics and (2) local human activities during the 2nd millenia BC. into the Nile delta.

Lead isotopes, luminescence datings and sediment analysis allow to correlate fluctuations of the delta hydrosystem to regional climate shifts such as the transition from late Pleistocene deposits to more recent Holocene alluvia. Pb isotopes in sediments deposited prior to the onset of the Hyksos city display non contaminated imprints spread between several natural sources. This distribution illustrates transient changes in the Nile hydrodynamics and prevailing climatic settings. Here are also presented anthropogenic signals identified during the Bronze Age in the Eastern Nile delta.

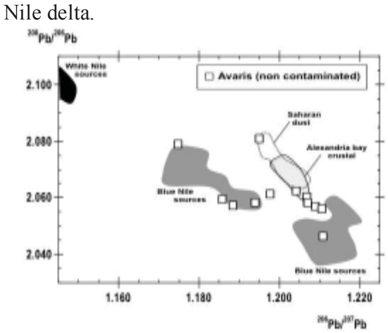

Figure 1: Distribution of the natural Pb isotope imprints at Avaris

[1] Doe, B.R. (1970) *Lead isotopes*, Springer-Verlag, Berlin, 137p.