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10 years of Lusi eruption: Lessons learned from multidisciplinary studies (LUSI LAB)

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ABSTRACT

The spectacular Lusi eruption started in northeast Java, Indonesia, on May 29th, 2006, continuously erupting mud, water, gas, oil, and clasts ever since. Lusi provides an unprecedented opportunity to study the birth and the evolution of a large-scale and hot mud eruption. Lusi is interpreted as a hybrid between a traditional hydrocarbon-driven piercement structure (mud volcano) and a hydrothermal system fuelled by magmatic heat. Lusi is therefore an exciting natural laboratory for understanding analogue modern and palaeo-piercement systems such as mud volcanoes, sediment-hosted hydrothermal systems, and hydrothermal vent complexes.

This special issue collects recent multidisciplinary work completed in the framework of the ERC-funded LUSI LAB project. These studies were conducted at and near Lusi. Contributions span across disciplines such as engineering, geochemistry, geophysics, geology and numerical modelling, including fieldwork, laboratory and theoretical approaches. The acquired results contribute to characterise the dynamics of complex interactions between volcanism and an ongoing erupting clastic system. Lusi still saves many mysteries that will be unravelled by future scientific investigations.

1. Introduction

The 29th of May 2006 witnessed the sudden birth of numerous vents around the Sidoarjo district in NE Java, Indonesia. Field observations document that after a strike slip crustal M6.3 earthquake striking the Java island the 27th of May 2006, a system of fractures appeared in the Sidoarjo region together with several aligned eruption sites (Mazzini et al., 2007). The distribution of these active vents extended over a distance of more than a kilometre forming an alignment striking NE-SW. Within days a prominent crater formed and other vents were quickly covered by the large amount of boiling mud erupted (flow rate peaking at up to 180,000 m^3/day). This new structure was named Lusi [acronym from **LU**mpur (mud) and **SI**doarjo (the district name)]. The orientation of the fractures and the eruptions followed the trend of the reactivated Watukosek fault system (WFS). The WFS originates from the Arjuno-Welirang volcanic complex and extends towards the NE in the Java backarc sedimentary basin. Within weeks, several villages were submerged by boiling mud forcing the evacuation of 60,000 people, ultimately covering an area of more than 7 km^2 with erupted mud breccia (Fig. 1A–B). The social impact of the eruption and its spectacular dimensions still attract the attention of international media reporting on the "largest mud eruption site on Earth". To date, after nearly twelve years, Lusi is still active and erupting gas, water, oil, mud and clasts from two, and sometimes three active vents (Fig. 1B and Fig. 2).

2. The LUSI LAB project

Since its inception Lusi has attracted the attention of scientists and numerous dedicated studies have been completed in the framework of the LUSI LAB project. LUSI LAB (ERC grant n° 308126, PI A. Mazzini) is an ambitious project that performed a multidisciplinary study using Lusi and the neighbouring region as a unique natural laboratory. The objective of the project is to 1) use the newly born and currently ongoing Lusi eruption to better understand the processes underway in the active conduit, and 2) to investigate the interaction between seismicity, faulting, volcanic activity and igneous intrusions. Particular emphasis was aimed at unravelling many unanswered questions: what lies beneath Lusi? If Lusi is not a mud volcano, what is the nature of the link between Lusi and the connected hydrothermal system? How the frequent seismic activity and the neighbouring Arjuno Welirang volcanic complex affect the pulsating behaviour of Lusi? What are the mechanisms controlling the eruption? How long will the eruption last? Are more eruptions like this one to be expected in the future?

LUSI LAB developed a network of scientific collaboration with numerous international institutes (see Acknowledgments for details).

The research team focussed on five main aspects in order to complete a comprehensive regional investigation: 1) development of new technologies to reach the active crater and perform sampling and areal investigations; 2) monitoring and sampling the neighbouring volcanic arc and the active Lusi vents; 3) monitoring of the fault system that originates from the volcanic arc, crosses Lusi and extends to the NE of Java Island; 4)

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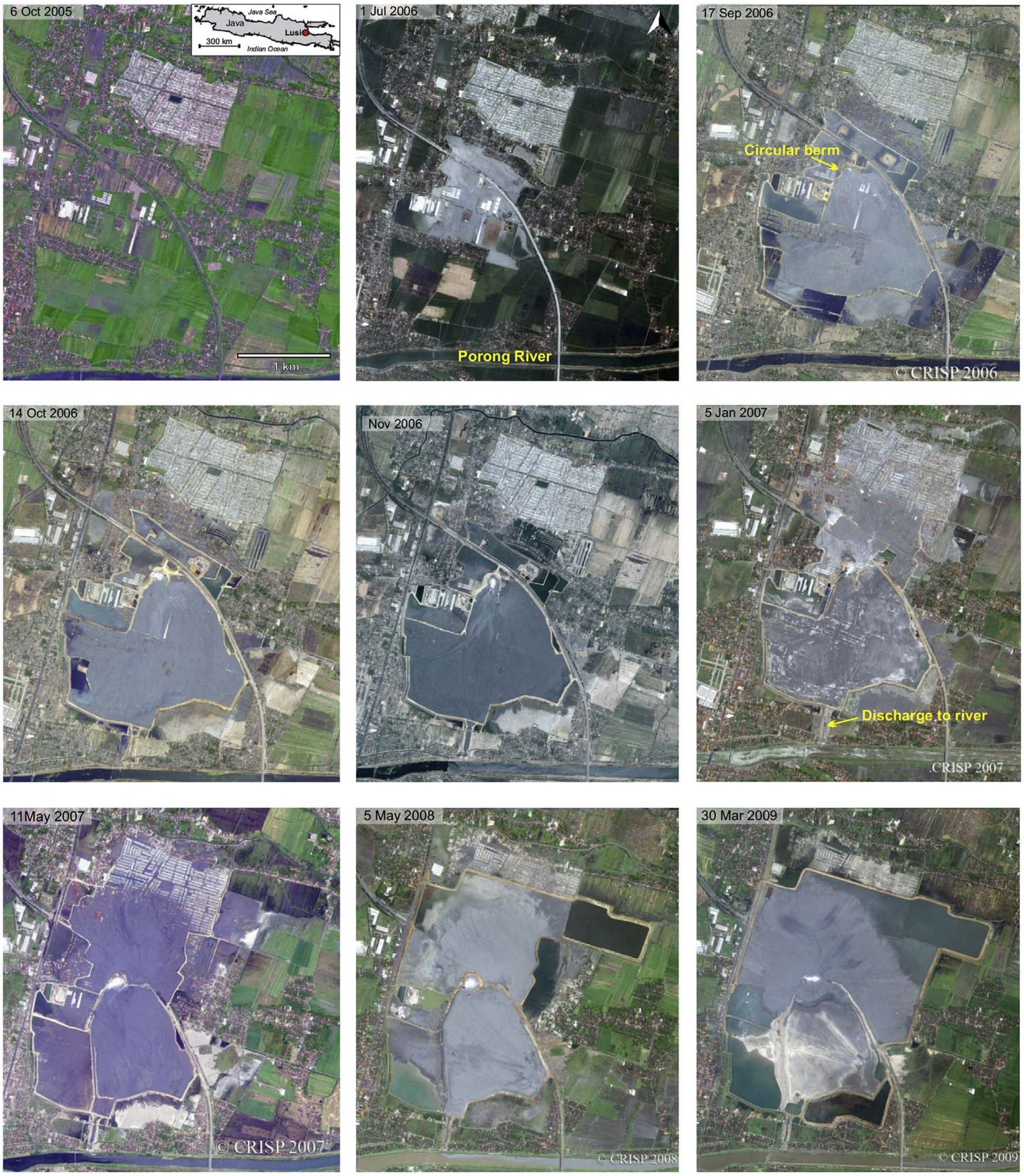

Fig. 1. A–B: Satellite images from Google Earth and CRISP (NUS) of the area around Lusi eruption site (period 2005–2017). Inset map of Java Island with the Lusi position (red dot). During the years numerous embankments have been constructed with the attempt to contain the erupted mud. Despite the continuous discharge of mud into the Porong River located to the south of Lusi, the mud covered area became larger and larger. To date (Dec. 2017) a surface of nearly 7 km^2 is framed by a 10 m tall embankment that contains the erupted mud breccia. Since 2010 two active vents are actively erupting. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

geophysical observations, gravity survey, and regional 2D seismic studies; 5) clasts dating and petrography observations; 6) monitoring local micro-seismicity potentially related to regional seismicity; 7) numerical modelling of Lusi activity and the strike-slip/magmatic complex system; 8) up-scaling the results obtained at Lusi for larger modern and palaeo systems.

After the first field study reported by Mazzini et al. (2007), Mazzini et al. (2009) proposed a hypothesis for Lusi's birth. The results highlighted that a WFS lateral shearing occurring after the 27th of May 2006 M 6.3 earthquake provided the pathway for the rise of fluids. The strike slip movement facilitated the fluidization of overpressured units along the faulted region and allowed the sudden release of fluids and clasts to the surface triggering the eruption of Lusi. The findings combine field measurements and observations with analogue modelling supporting this scenario.

The origin of the erupted fluids was investigated by Mazzini et al. (2012). The authors provide an extensive database of geochemical analyses highlighting that the erupted gas has both sedimentary and mantellic components. Further, the processes leading to the generation of CH_4 and CO_2 erupted at the crater require formation temperature up to 400 °C. These elevated temperature values are inconsistent with the geothermal gradient measured in the area prior to the eruption, hence an additional heat source had to be invoked. This led the authors to change the paradigm of Lusi, previously considered as a mud volcano, and introduce the term “sediment-hosted hydrothermal system”. This evidence implies the migration of magma and hydrothermal fluids towards the backarc sedimentary basin, triggering thermo-metamorphic reactions altering the organic-rich