Earth and Planetary Science Letters 317–318 (2012) 305–318

Contents lists available at SciVerse ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

A new hydrothermal scenario for the 2006 Lusi eruption, Indonesia. Insights from gas geochemistry

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ARTICLE INFO

Article history:
Received 5 July 2011
Received in revised form 17 November 2011
Accepted 18 November 2011
Available online 29 December 2011

Editor: R.W. Carlson

Keywords:
Lusi eruption
sediment-hosted hydrothermal system
mud volcanoes
gas origin
CO_2 and CH_4
mantle

ABSTRACT

The 29th of May 2006 gas and mud eruptions suddenly appeared along the Watukosek fault in the north east of Java, Indonesia. Within a few weeks several villages were submerged by boiling mud. The most prominent eruption site was named Lusi. To date (November 2011) Lusi is still active and a ~7 km^2 area is covered by the burst mud breccia.

The mechanisms responsible for this devastating eruption remain elusive. While there is consensus about the origin of the erupted mud, the source of water is uncertain, the origin of the gas is unknown and the trigger of the eruption is still debated. In order to shed light on these unknowns, we acquired a wide set of data of molecular and isotopic composition of gas sampled in several Lusi vents, in the surrounding mud volcanoes, in the closest natural gas field (Wunut), and in the hydrothermal vents at the neighbouring volcanic complex in the period 2006–2011.

The boiling fluids erupted in the crater zone are apparently CO_2-dominated, while colder CH_4-dominated and C_2–C_3 bearing fluids are identified at several sites around the crater zone. Gas genetic diagrams, maturity plots and gas generation modelling suggest that the hydrocarbons are thermogenic ($\delta^{13}C_1$ up to −35‰; $\delta^{13}C_2$ up to −20‰), deriving from marine kerogen with maturity of at least 1.5%Ro, for instance in the ~4400 m deep Ngimbang source rocks. CO_2 released from the crater and surrounding seeps is also thermogenic ($\delta^{13}C$ from −15 to −24‰) related to kerogen decarboxylation or thermal CH_4 oxidation in deep rocks, although three vents just outside the crater showed an apparent inorganic signature ($-7.5‰ < \delta^{13}C = -0.5‰$) associated to mantle helium (R/Ra up to 6.5). High CO_2–CH_4 equilibrium temperatures (200–400 °C) are typical of thermally altered hydrocarbons or organic matter. The data suggest mainly thermally altered organic sources for the erupted gases, deeper sourced than the mud and water (Upper Kalibeng shales). These results are consistent with a scenario of deep seated (>4000 m) magmatic intrusions and hydrothermal fluids responsible for the enhanced heat that altered source rocks and/or gas reservoirs.

The neighbouring magmatic Arjuno complex and its fluid–pressure system combined with high seismic activity could have played a key role in the Lusi genesis and evolution. Within this new model framework, Lusi is better understood as a sediment-hosted hydrothermal system rather than a mud volcano.

1. Introduction

The 29th of May 2006 the Sidoarjo district in East Java, Indonesia witnessed the sudden birth of numerous gas and mud vents on the ground. These eruption sites extended over a distance of more than a kilometre forming a NE–SW alignment. Within a few days a prominent crater formed and the initial vents were quickly covered by the large volumes of erupted boiling mud. The flow-rates from the main crater reached 180.000 m^3/day (Mazzini et al., 2007). The largest crater was named Lusi [acronym from *LU*mpur (mud) and *SI*doarjo (the district name)]. To date (November 2011) Lusi is still active and has since 2006 gained the constant attention of the media due to the spectacular nature of the eruption that devastated and submerged villages, displaced more than 50,000 people and covered a region of more than 7 km^2 by hot mud (Fig. 1).

The trigger of the Lusi eruption remains debated. One hypothesis links Lusi to a blowout from a neighbouring well (Davies et al., 2007; Tingay et al., 2008), whereas others have confuted the "man-made" scenario (e.g. Sawolo et al., 2009, 2010). An alternative hypothesis links the eruption events to the reactivation of a fault following a 6.3 M earthquake that struck the Java Island the 27th of May 2006 (Mazzini et al., 2007, 2009; Tanikawa et al., 2010). More than five years after the birth of Lusi, we stress that the geological knowledge of the Lusi region and the neighbouring areas shows that: 1) The presence of a NE–SW oriented fault (Watukosek fault, Fig. 1) that originates from the neighbouring Arjuno–Welirang volcanic complex, crosses Lusi and extends towards the NE of Java. Field observations showed that lateral shearing

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doi:10.1016/j.epsl.2011.11.016

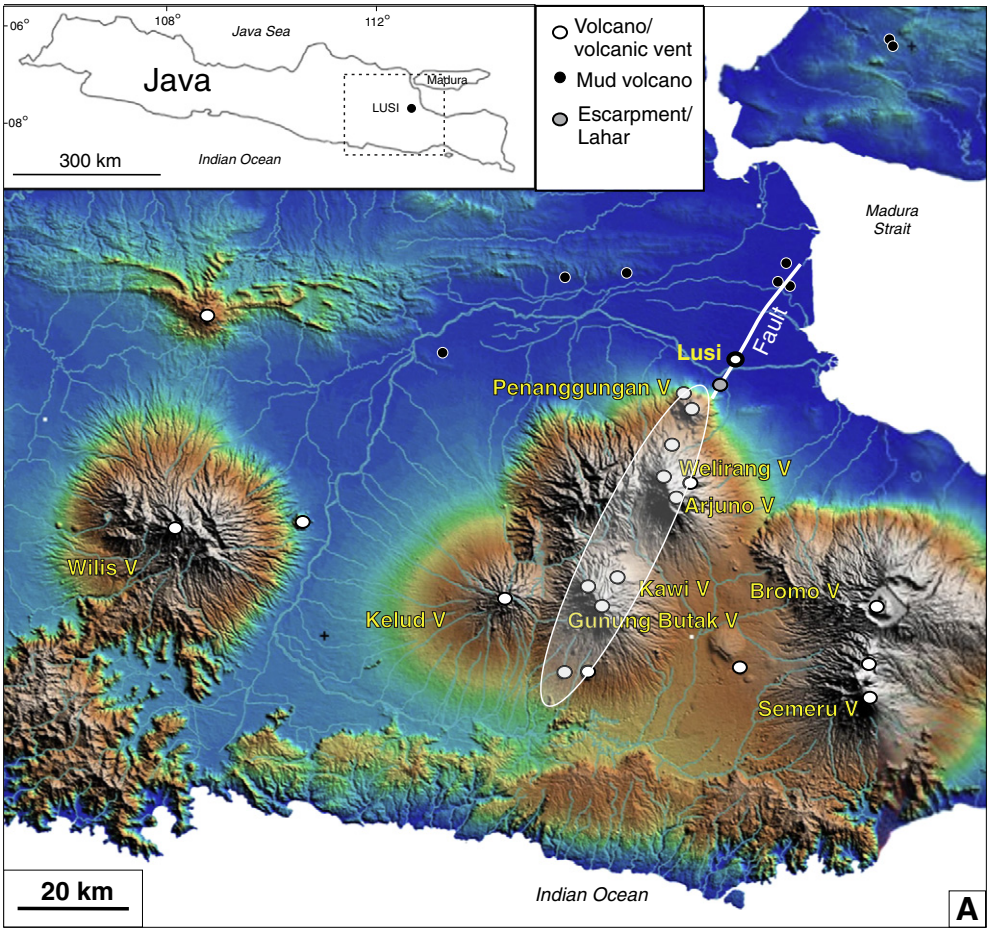

Fig. 1. (A) Elevation map of eastern Java Island. Highlighted the position of some known mud volcanoes, and main volcanoes and volcanic vents. Note: the orientation of the main vents of the Arjuno–Welirang volcanic complex has the same NE–SW direction of the Watukosek fault that also hosts a large escarpment as well as other mud volcanoes; (B) satellite image of Lusi the 14 of June 2011, courtesy of Crisp, NUS 2011. Note the brownish areas on the outskirts of the crates represent dry zones where it is possible to access. The central part closer to the crater remains muddy.