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Research paper

More than ten years of Lusi: A review of facts, coincidences, and past and future studies

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ABSTRACT

The Lusi mud eruption in East Java, Indonesia, has continued unabated for more than ten years with no end in sight. This review summarizes what has been learned about this intriguing system, from its inception to the current (2017) well-established metastable geysering system that continuously erupts mud breccia, gas, steam, and water. We discuss the initiation of Lusi, highlighting discrepancies and evidence through the published data, to build a comprehensive database that emphasizes how the results converge towards a natural scenario of this system. We argue that attempts to understand, constrain, or predict the behaviour of this system that rely on a drilling trigger can not explain subsequent observations. On the other hand, we show that a well-constrained conceptual model recognizing Lusi as a volcanically-linked hydrothermal system, has provided important insights for the documented observations over the last eleven years. The response of Lusi to the Yogykarta earthquake falls directly within the range of earthquake triggering phenomena (globally) of similar hydrothermal/geothermal systems, suggesting a natural trigger as the more likely culprit for the Lusi phenomenon. We also offer some future directions of additional scrutiny for understanding this newborn, tectonic scale, volcanic-hydrothermal complex.

1. Introduction

The Lusi (**LU**mpur = "mud" in Indonesia Bahasa; **SI**doarjo = the local Regency where the eruption occurred) mud eruption that appeared in East Java the 29th of May 2006 elicited debate, science, and politics (Drake, 2016; Van Noorden, 2006). Less than two days after a powerful earthquake struck and decimated Yogyakarta, 250 km to the southwest, and with all eyes focused there, mud started coming through the surface at five different locations near Surabaya, East Java (Mazzini et al., 2007). The mud first appeared along a thousand meter lineament that, incidentally, follows the same trend of the adjacent Watukosek fault system (Figs. 1–3). This is a tectonic-scale sinistral strike-slip fault that runs from the nearby Arjuno-Welirang volcanic complex directly through the region, hosting many pre-historic mud eruptions (Istadi et al., 2009; Mazzini, 2009; Mazzini et al., 2009; Moscariello et al., 2017; Satyana, 2008; Sciarra et al., 2017) (Fig. 2). Gas and mud first appeared as small vents through cracks formed in the ground, likely in response to slip on the Watukosek fault system (Figs. 1–3). This diffuse pattern soon gave way to focused geysers and a relentless eruption of mud breccia, water, and gas. The mud quickly overtook an urban area near the city of Sidoarjo, permanently displacing 60,000 persons (Richards, 2011), while swallowing the main highway linking East Java to the rest of the Island (Figs. 2 and 4). And the mud kept coming, emitting up to 180,000 m^3/day with powerfully erupting plumes. Nothing could stop it. Thousands of concrete spheres chained together were lowered into the throat hoping to choke the flow (Mazzini et al., 2007) but the eruption continued unabated. Attempts to cement the upwelling of fluids at depth using a relief well also failed due to the continuous shearing of the fractured zone (Sutrisna, 2009). Berms built to contain the mud (Fig. 4) evolved to 10 m high embankments that now surround Lusi framing a region of ~7 km^2. That is, a 7 km^2 swimming pool filled with erupted mud breccia, which could unleash the next disaster were the embankment walls to fail (Fig. 1B).

More than ten years later the mud keeps coming, with Lusi now a perpetual geyser system Karyono et al., 2017 hosting two (since 2010) and, sometimes three, migrating main vents that erupt with enhanced activity on timescales of several minutes. The recent flow

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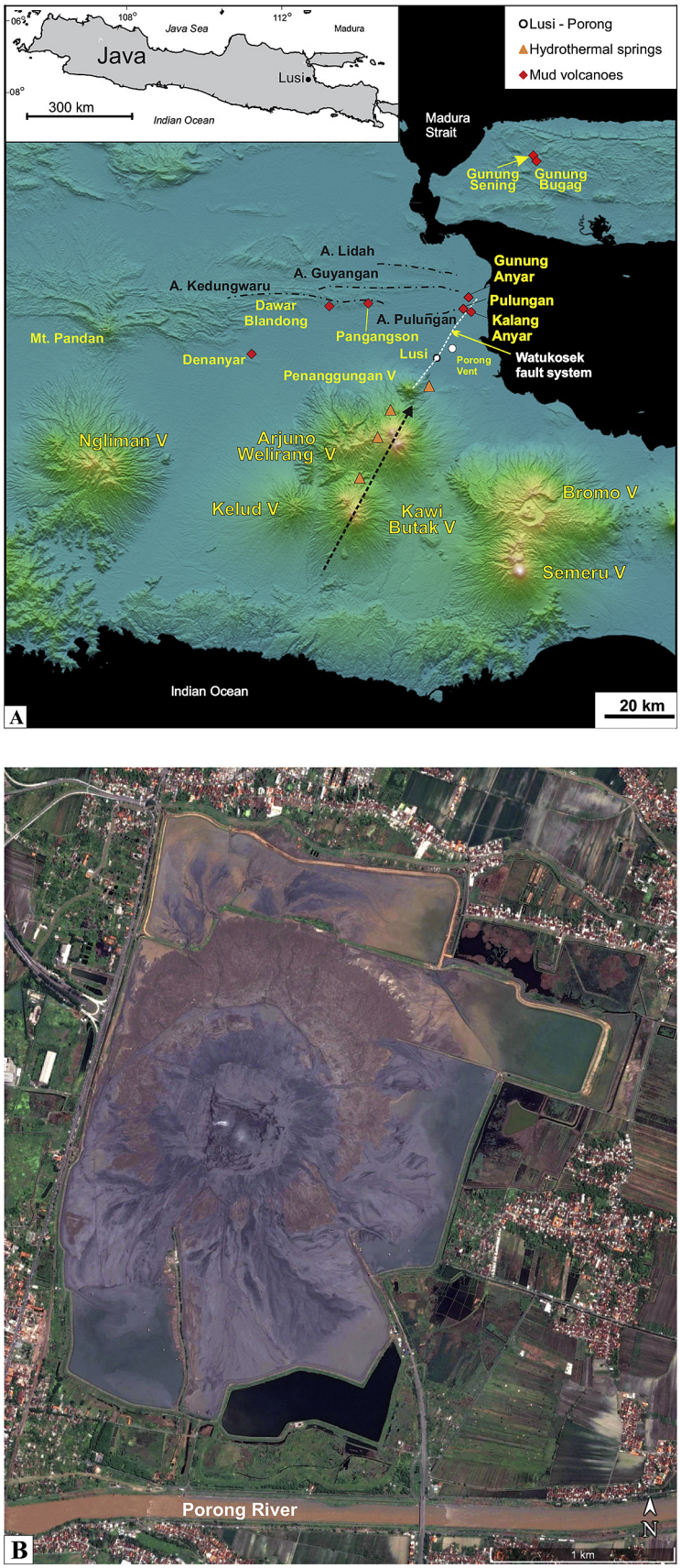

Fig. 1. (A) Elevation map of eastern Java Island, highlighting the locations of some known mud volcanoes and main magmatic volcanoes. Note: the NE–SW direction growth of the eruptive vents of the Arjuno–Welirang volcanic complex and the distribution of the hydrothermal springs is the same of the Watukosek fault system that also hosts a large escarpment as well as other mud volcanoes; Lusi and the Porong sites are also indicated. The Porong piercement is interpreted to be a paleo collapse of an ancient hydrothermal system now imaged with seismic reflection data (Istadi et al., 2009). (B) Satellite image of Lusi site in 2016. Note the framing embankment wall. The brownish areas on the outskirts of the active vents represent dry zones where it is possible to access. The central subcircular zone around the vents consists of not accessible liquid mud breccia.

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