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Discussion

An alternative review of facts, coincidences and past and future studies of the Lusi eruption

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ABSTRACT

The cause of the Lusi mud eruption remains controversial. The review by Miller and Mazzini (2017) firmly dismisses a role of drilling operations at the adjacent Banjarpanji-1 well and argues that the eruption was triggered by the M6.3 Yogyakarta earthquake some 254 km away. We disagree with these conclusions. We review drilling data and the daily drilling reports, which clearly confirm that the wellbore was not intact and that there was a subsurface blowout. Downhole pressure data from Lusi directly witness the birth of Lusi at the surface on the 29th of May 2006, indicating a direct connection between the well and the eruption. Furthermore, the daily drilling reports specifically state that Lusi activity was visibly altered on three separate occasions by attempts to kill the eruption by pumping dense fluid down the BJP-1 well, providing further evidence of a connection between the wellbore and Lusi. By comparison with other examples of newly initiated mud eruptions elsewhere by other earthquakes, the Yogyakarta earthquake was far away given its magnitude. The seismic energy density of the Yogyakarta earthquake was only 0.0043 J/m^3, which is less than a quarter of the minimum 0.019 J/m^3 seismic energy density that has ever been inferred to trigger other mud eruptions. We show that the Lusi area had previously experienced other shallow earthquakes with similar frequencies and stronger ground shaking that did not trigger an eruption. Finally, the data from the BJP-1 well indicates that there was no prior hydrodynamic connection between deep overpressured hydrothermal fluids and the shallow Kalibeng clays, and that there was no evidence of any liquefaction or remobilization of the Kalibeng clays induced by the earthquake. We thus strongly favor initiation by drilling and not an earthquake.

1. Introduction

Lusi has been a fascinating laboratory for studying the birth and evolution of large mud eruptions. The triggering of this unique disaster has been highly controversial, with some studies proposing that the disaster is man-made due to a drilling accident (e.g. Davies et al., 2007, 2008; Tingay et al., 2008), while other studies propose a natural earthquake trigger for the eruption (e.g. Mazzini et al., 2007; Sawolo et al., 2009; Lupi et al., 2013). To interpret observations made during this eruption, especially during the early stages of the eruption, we contend that it is essential to understand the processes that initiated the eruption. Ten years after the eruption began is an appropriate time to look backwards at what we have learned. In the review by Miller and Mazzini (2017), the eruption is attributed to an earthquake and the authors argue that the nearby drilling operations at the Banjarpanji-1 (BJP-1) well played no role.

It is important to highlight that, despite the claims made by Miller and Mazzini (2017), the drilling-trigger and earthquake-trigger models are very similar, and only differ on two key issues. Both hypotheses argue that something changed the effective stress (stress minus pore fluid pressure) on faults or fractures under Lusi, causing those faults or fractures to become active and permit fluid flow to the surface. The earthquake and drilling triggering mechanisms differ on two main points:

1) What caused the change in effective stress under Lusi? Drilling-trigger proponents argue that the change in effective stress was the large pressure increase in the BJP-1 borehole that occurred when the well was shut-in during a kick (an influx of fluid) on the 28th of May 2006 (resulting in a minimum effective stress decrease of 2.6 MPa; Davies et al., 2008; Sawolo et al., 2009). Earthquake trigger proponents argue that the change in effective stress was the result of gas

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release due to liquefaction of the Kalibeng clays, with this liquefaction being triggered by the dynamic shaking from the passage of seismic waves from the 27th May 2006 Yogyakarta event (resulting in a maximum effective stress reduction of 0.2 MPa, less than 1/13th the effective stress change caused by the kick; Lupi et al., 2013).

2) What was the primary initial source of high-pressure water driving the initial eruption, and, specifically, were the Kalibeng clays hydrodynamically connected to deep overpressured fluids prior to the Lusi eruption? Drilling-trigger proponents argue that the water that primarily drove the start of the Lusi eruption was sourced from the deep carbonates at ~2800 m depth (which are directly connected to a deep overpressured, and possibly hydrothermal, system), and that the kick in BJP-1 allowed these fluids to use the borehole to flow up into the Kalibeng clays, entraining these clays as they flowed through fractures to the surface. This model suggests no prior hydrodynamic connection between the Kalibeng clays and deeper waters (though does not specifically preclude such a connection). In contrast, the earthquake trigger proponents argue that the Kalibeng clays had been previously 'charged' by deep overpressured and hydrothermal fluids via the Watukosek fault, and claim that hydrothermal fluid invasion would make the Kalibeng clays susceptible to liquefaction or mobilization. Published earthquake-triggering models specifically require the Kalibeng clays to be in hydrodynamic connection prior to the Yogyakarta earthquake (Mazzini et al., 2012; Lupi et al., 2013).

These two issues are essentially the key to distinguishing between the earthquake- and drilling-trigger arguments, as summarized in Fig. 1.

Here we provide a chronology and explanation of the published data from daily reports and drilling logs. We then update previous compilations of earthquake-triggered eruptions. Together these analyses allow us to critically assess all the key claims in Miller and Mazzini (2017) that an earthquake triggered the eruption. In particular, the highly detailed analysis of the original daily drilling reports and data undertaken herein highlights major pieces of evidence that have been overlooked in prior studies, such as the multiple instances in which drilling reports document a direct connection between Lusi and the BJP-1 well. We argue, instead, that the extensive evidence strongly supports the drilling-trigger model, and contradicts the earthquake-triggering model.

2. Drilling

Miller and Mazzini (2017) do not bring any new data to the argument that drilling did not create the Lusi mud volcano, and repeat the claims made by Sawolo et al. (2009, 2010), which were primarily authored by the Lapindo Brantas engineers who drilled the BJP-1 well.

All key observations related to drilling the BJP-1 well, and of the first days of the Lusi eruption, are documented in the daily drilling reports, and were published previously as online appendices to Sawolo et al. (2009). We summarize these observations and show the daily drilling reports for the 24-h periods ending at 5 a.m. on the 27th to 31st of May 2006 (Figs. 2–6). These reports directly contradict most of the key statements in Miller and Mazzini (2017) and the key claims made in Sawolo et al. (2009, 2010). It is the official original drilling data and daily drilling reports, as well as other (published) data, that form the basis of the arguments made by proponents of the drilling-trigger hypothesis for Lusi (Davies et al., 2007, 2008; 2010; Tingay et al., 2008, 2015).

We argue that the original well report statements and raw drilling data presented herein demonstrate conclusively that the wellbore was fractured during the kick, suffered large ongoing downhole losses for long periods after the kick commenced, and that there was direct communication between the BJP-1 wellbore and Lusi eruption. These processes are described in Claims 4 and 7 below, and are the key evidence supporting a drilling-trigger for the Lusi disaster. However, we also discuss all major claims made by Miller and Mazzini (2017) and Sawolo et al. (2009) and show that their claims require readers to ignore large parts of the original drilling records and reports.

We do not discuss many other claims in Miller and Mazzini (2017), such as production rate changes in nearby hydrocarbon wells and reported drops in water levels in villages, as these are anecdotal statements for which no supporting evidence has ever been published, and hence cannot be verified or quantitatively assessed. The claims below are listed in chronological order. We first summarize each claim, explain why it matters, review the evidence, and provide a conclusion about each claim.

We use a clear hierarchy of data in our assessment. We consider raw data and the BJP-1 daily reports to be the most reliable data, as these reports list observations and routine calculations made at the time of events. Furthermore, we give greater confidence to evidence, statements and observations that are confirmed in multiple sources (e.g., stated in multiple daily reports, or on both reports and raw data). It should be noted that such daily reports are generally classified as legal documents, that are confirmed and signed off for their accuracy by multiple sources, and have been included within legal proceedings related to the Lusi disaster (Novenanto, 2015). Such raw data should always be considered more robust and reliable than claims, statements or interpretations made significantly after the events at BJP-1, which have the potential to be affected by biases and, in some cases, are not supported by any verifiable data.

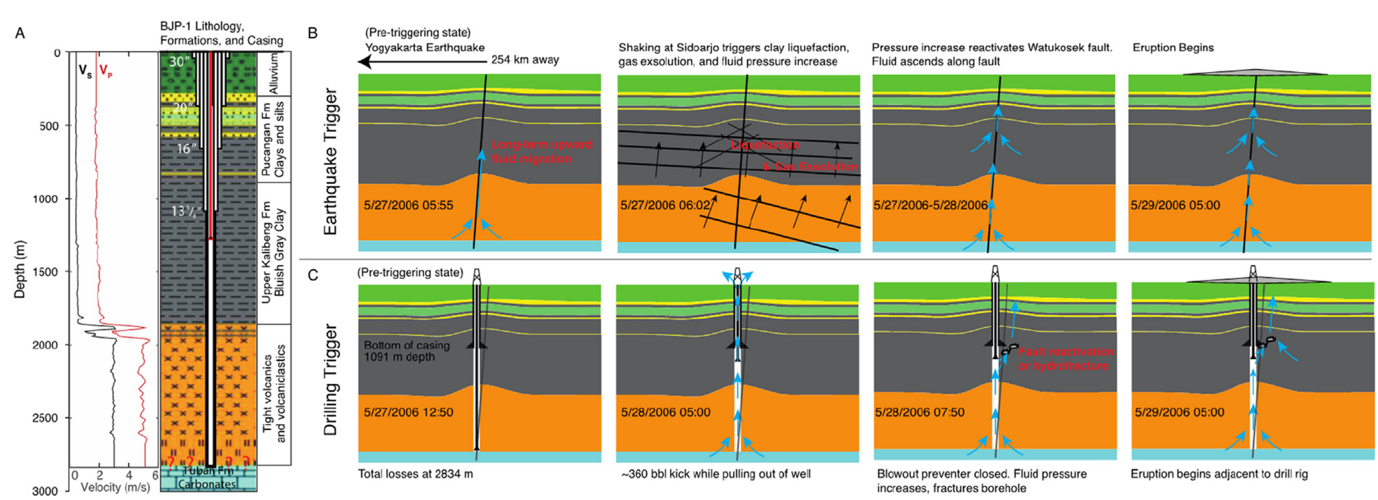

Fig. 1. Schematic illustration of the two models for the initiation of the 2006 Lusi eruption.