Marine and Petroleum Geology xxx (2017) 1–12

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Insights on the structure of Lusi mud edifice from land gravity data

Guillaume Mauri [a,*], Alwi Husein [b,c,d], Adriano Mazzini [b], Dwinata Irawan [d], Reza Sohrabi [a], Soffian Hadi [d], Hardi Prasetyo [d], Stephen A. Miller [a]

[a] University of Neuchâtel, Switzerland
[b] CEED, University of Oslo, Oslo, Norway
[c] Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[d] Badan Penanggulangan Lumpur Sidoarjo, Sidoarjo, Indonesia

ARTICLE INFO

Article history:
Received 24 December 2016
Received in revised form
22 May 2017
Accepted 31 May 2017
Available online xxx

Keywords:
Mud volcano
Gravimetry
Potential field

ABSTRACT

Since May 2006, the active Lusi mud eruption has continuously erupted boiling mud. During the early stages of the eruption in 2006, previous gravity studies showed that the piling up of the mud constructed a large edifice that subsides within the unconsolidated sediment especially around a large area over the active crater. After ten years of continuous eruption, the size of the edifice has grown significantly over a surface framed by 10 m tall containment embankments. In 2015 and 2016, several land gravity surveys were carried out to investigate the structure of the mud edifice and the effect of local geological active features. The new residual Bouguer anomaly map, calculated for a reference density of 2670 kg m^{-3}, shows significant changes in the local gravity field in comparison to the previous 2006-gravity map survey. The new data set shows that the gravity decrease is generally restricted along the faulted and fractured zones, around erupting vents, and in the southern part of the mud edifice. Maximum gravity variations reach 1.4 mGal in some areas of the mud edifice. In the region outside the embankment, the gravity reductions are 0.6 mGal E-W and 1.0 mGal N-S. A second vertical derivative analysis of gravity data indicates that the mud edifice continues to pile up and subside mostly in the western and southern part of the edifice. Results of a 3D forward model of a vertical cylinder shape allowed characterising the extent of compacted material along the Watukosek fault system that originates from the neighbouring volcanic arc and crosses the mud edifice. Our results support the hypothesis of local pinched volume of mud ongoing between the subsided and uplifted masses of mud. The density of compacted mud breccia material increases between 16 and 27%. Gravity data also shows that the Lusi mud edifice is built over an extended NW-SE gravity increase, interpreted as a sediment density variation within the basin, and which is parallel to the trend of the Basin.

1. Introduction

In May 2006, following a M6.3 earthquake event in Central Java, Merapi and Semeru volcanoes in Central and East Java showed increased activity (Mazzini et al., 2009). Simultaneously, in an urban area in the south of Sidoarjo, numerous mud eruptions appeared at the surface, ultimately resulting in the birth of the Lusi mud eruption (Mazzini et al., 2007; Sawolo et al., 2009). Lusi has been described as a newborn, tectonic scale, sediment-hosted hydrothermal system linked to the adjacent volcanic complex in the south (Mazzini et al., 2012; Sawolo et al., 2009). Geochemical and other evidence collected over the years indicate that the mud eruption is evolving towards a steady and continuing geyser system (Mazzini et al., 2012; Vanderkluysen et al., 2014; Karyono et al., 2016). To date, the Lusi system is still very active and covers a surface of 7 km^2, surrounded by 10 m-high embankments that protect a densely populated region (Fig. 1). The mud level almost reaches the top of the embankment in the western part of the mud field, while the piling mud layers are subsiding along the active vents area (Istadi et al., 2009, 2012). While a large part of the mud is flushed away to the Porong River through pipelines, other portions are building large mud edifices. In the last 11 years of persistent eruption, several tens of thousands of cubic meters of boiling med discharged daily (Mazzini et al., 2007, 2012; Davies et al., 2011; Mazzini and Etiope, 2017). The Lusi mud edifice is composed of mud breccia consisting of a mix of fine-grained sediments and

* Corresponding author.
E-mail address: guillaume.mauri@unine.ch (G. Mauri).

http://dx.doi.org/10.1016/j.marpetgeo.2017.05.041

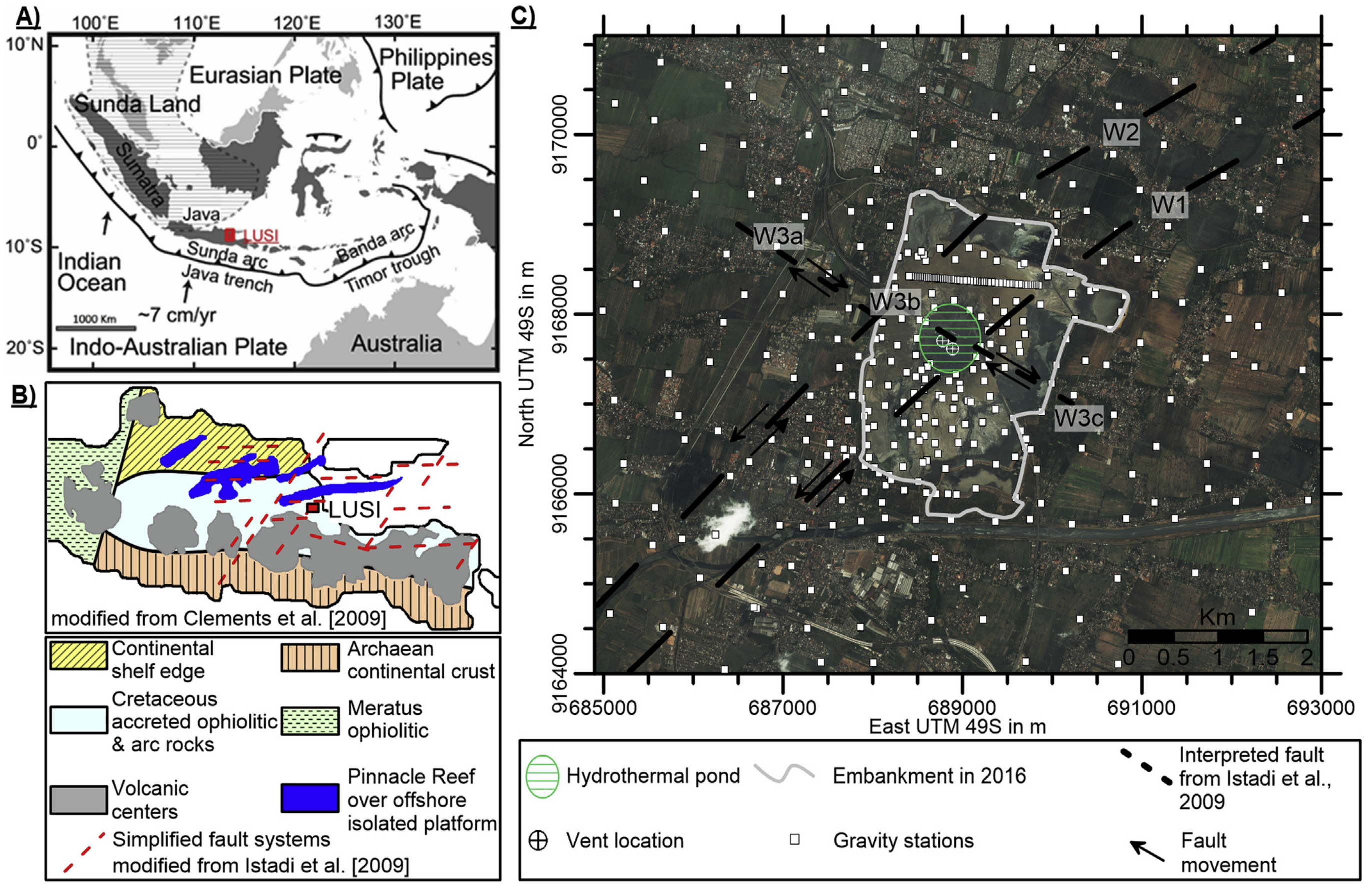

Fig. 1. Location of Lusi mud field, in the east part of East Java, Indonesia. A) Simplified tectonic setting of SE Asia (Hamilton, 1979; Tregoning et al., 1994; Syracuse and Abers, 2006), modified from Vigouroux et al. (2012). B) Simplified structural map of East java (Smyth et al., 2007; Clements et al., 2009; Istadi et al., 2009). C) Satellite view of Lusi with fault structures (W1, W2, W3a-c), as presented in the work of Istadi et al. (2009). Satellite Image Ortho-photo©CNES 2015. Location of the 390 gravity stations on Lusi mud field and its surrounding collected between November 2015 and November 2016.

clasts that originate from the underlying sedimentary units (Istadi et al., 2009; Mazzini et al., 2012). The embankment breached at several locations (Mazzini et al., 2012) over the years.

Lusi is a geologic rarity. She may represent an opportunity to exploit geothermal energy, or pose a potentially catastrophic hazard if the embankments are breached or the mud liquefies in response to local or regional earthquakes. Therefore constraining this system, understanding this system, is paramount.

Previous geophysical works showed: 1) prior to Lusi birth, the underlying sedimentary layers revealed piercement structures of on-going diapir-like growth toward the surface (Mazzini et al., 2009), 2) the Lusi mud edifice is thickening toward its center (Istadi et al., 2009), due to subsidence controlled by isostatic equilibrium of the piling mud along collapse structures, 3) mud layers have heterogeneous conductivity properties associated to fault and water content (Istadi et al., 2009), 4) geyser activity is likely associated with a reservoir at depths between 1.2 and 1.7 km (Vanderkluysen et al., 2014; Karyono et al., 2016).

Previous gravity studies performed in 2006 highlighted a circular collapse structure centred on Vent #1 (Istadi et al., 2009). The 2006-collapse structure was characterized by a local gravity decrease of 0.6–0.8 mGal in amplitude and spread over an area of about 1 km × 1 km (Istadi et al., 2009). In addition, previous dynamic gravity surveys revealed mass displacement associated to the eruption.

In this paper, we adopt the term "mud field" to characterize the mud surface surrounded by the embankment and the term "mud edifice" to refer to the whole volume of mud from the surface to depth. The term "hydrothermal pond" refers to the area made of liquid mud that surrounds the two main vents.

The aim of the present study is to investigate changes in the local gravity field to, 1) get insight on the basin structure in the area of Lusi mud edifice, 2) characterize the relationship between the sedimentary structure of the basin and Lusi edifice, 3) characterize the evolution of the collapse structure ten years after its birth, 4) provide insight into possible changes in the fault structures intersecting the area, and 5) provide new insights on the thickening of the mud edifice for future constraints on 3D numerical models.

2. Geological setting

Lusi is located on the eastern part of Java Island that is part of the Sunda arc and about 250 km North of the Sunda subduction trench (Fig. 1A) (Moore et al., 1996; Setijadji, 2010). The subduction of the Indo-Australian plate beneath the Eurasian plate began about 50Ma. The margin is moving northward, with a subduction rate of approximately 7 cm/year (Malod and Kemal, 1996; McCaffrey, 1996; Simandjuntak and Barber, 1996). East Java can be divided into 3 distinct structures that are, from south to north: 1) Archean continental crust, 2) Cretaceous accreted ophiolites and volcanic arc rocks, and 3) continental shelf edge (Smyth et al., 2005, 2007; Clements et al., 2009; Hall, 2011). Ophiolite and arc rock structures are separated from the continental shelf by the Kendeng Thrust fault system (oriented W-E) (Clements et al., 2009; Istadi et al.,

Please cite this article in press as: Mauri, G., et al., Insights on the structure of Lusi mud edifice from land gravity data, Marine and Petroleum Geology (2017), http://dx.doi.org/10.1016/j.marpetgeo.2017.05.041