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GEOTHERMAL POTENTIAL AT LUSI MUD VOLCANO, INDONESIA

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ABSTRACT

Mud volcanoes are most abundant in areas with rapid sedimentation rates, active compressional tectonics, and the generation of hydrocarbons at depth. Typically they are also found in tectonic subduction zones, accretionary wedges, passive margins within deltaic systems and in active hydrothermal areas, collisional tectonic areas, convergent orogenic belts, active fault systems, fault-related folds, and anticline axes. The existence of mud volcanoes are controlled by tectonic activity where fluid escapes from areas undergoing complex crustal deformation as a result of transpressional and transtensional tectonics. Collisional plate interactions create abnormal pressure condition and consequently overpressured build up of deep sedimentary sediment which in turn result in formation of diapirs. Over pressured zones typically are under-compacted sedimentary layers which have lower density than the overlying rock units, and hence have an ability to flow. LUSI Mud Volcano is located about 10 km northeast of Penanggungan Mountain complex, in Renokenongo village, Porong District, Sidoarjo Regency, East Java. Its location is in the Southern part of the hydrocarbon prolific East Java inverted back-arc Basin formed during the Oligocene - Early Miocene, on the Eastern tip of the Kendeng Zone. The geology of the area is characterized by the rapid deposition of thick organic rich sediment as part of the Brantas delta, and is influenced by the extensional tectonic regime. The temperature at the surface on LUSI is 100 C. Natural heat within the earth is geothermal energy. Reliable power is generated from underground water which seeps below on LUSI location is feasible to develop as geothermal energy. Some rock fragmen in LUSI also shown material come from upper mantle or near by volcanic system. They are metasediment rock and little metamorphic rock.

***Key words**: mud volcano, strike slip fault, active compressional tectonics, active fault, geothermal*

INTRODUCTION

A mud volcano is formed by the escaping natural gas that rises to the surface when it finds a conduit through fractures and carries mud which has a lower density (identified in seismic as velocity intervals) than the surrounding sedimentary succession. Fluid, gas, and surface water are ejected in a cone shape like a mountain and forms craters, mud pools (salses) and cones (gryphons). Tectonic movement is very influential, as well as rapidly deposited sediments and burial of organic rich sediments. Strike-slip faults in active tectonic regions are the most ideal place for the formation of mud volcanoes.

Geological structures like faults and anticlines where mud volcanoes are commonly found are easily perturbed by earthquakes as they represent weak regions for the seismic wave's propagation. This mechanism is well described by Mellors et al. (2007) where earthquakes initiating local fluid movements cause fractures that propagate to the surface manifesting with a time delay from the main earthquake. Miller et al. (2007) proposed a link between earthquakes, aftershocks, crust/mantle degassing and earthquake-triggered large-scale fluid flow where trapped, high-pressure fluids are released through propagation of coseismic events in the damaged zones created by the main shock. The resulting disturbance of the gravitational instability triggers the beginning of flow, while the pressure drops and the lower cohesion media is easily fluidized and ultimately vacuumed to the surface through piercement structures which provide the conduits for high pressure mud/fluid and gas release.

BACKGROUND GEOLOGY

LUSI Mud Volcano is located about 10 km northeast of Penanggungan Mountain, in Renokenongo village, Porong District, Sidoarjo Regency, East Java (figure 1). Its location is in the Southern part of the hydrocarbon prolific East Java inverted back-arc Basin formed during the Oligocene - Early Miocene (Sribudiyani et al, 2003), on the Eastern tip of the Kendeng Zone (de Genevraye & Samuel, 1972). The geology of the area is characterized by the rapid deposition of thick organic rich sediment as part of the Brantas delta, and is influenced by the extensional tectonic regime (Willumsen and Schiller, 1994, Schiller et al, 1994). Due to the rapid deposition, shales in the area are undercompacted and overpressured (Mazzini et al., 2007). The geological condition is similar to the Caspian and the Black Sea areas where mud volcanoes are found (Planke et al, 2004, Mazzini et al., 2007; Tingay et al., 2008).

Java Island, located at the southern part of the Sundaland, was formed by rock assemblages associated with an active margin of plate convergence. The island has recorded plate convergence between the Australian plate and the Sundaland continental fragment since Late Cretaceous. Therefore, the island is made up of complex of plutonic-volcanic arcs, accretionary prisms, subduction zones, and related sedimentary rocks (Satyana and Armandita, 2004). The East Java geosyncline has thick Tertiary sediments of more than 6000 m (Koesoemadinata, 1980) with an estimated sedimentation rate of 2480 m/ma in the vicinity of LUSI (Kadar et al.,1997). The high sedimentation rates followed by rapid subsidence caused non-equilibrium compaction, and along with the maturation of organic materials resulted in the overpressured sediments within the Kendeng zone (see Willumsen and Schiller, 1994; Schiller et al., 1994). The overpressured sediments were later compressed, become mud diapirs and pierced the overlying sediments in many parts of East Java as mud volcanoes.

STRUCTURAL GEOLOGY AT LUSI MUD VOLCANO AND ITS SURROUNDING

The existence of mud volcanoes are controlled by tectonic activity where fluid escapes from areas undergoing complex crustal deformation as a result of transpressional and transtensional tectonics. The structural history in East Java basin where LUSI appear is divided into two phases: a Middle Eocene to Oligocene extensional phase, and a Neogene compressional or inversion phase. Grabens and half-graben structures were developed during the extensional phase, which was followed in the Neogene by compressional deformation with some wrenching. The most recent sedimentation in the East Java Basin occurred during the Late Pliocene to Holocene (3.6–0 Ma), during which time the southern part of the basin (Kendeng depression zone) was affected by north verging thrusts and uplift. The depression developed as a response to the isostatic compensation of the uplift of the southern Oligo-Miocene volcanic arcs. The uplift was accompanied by an influx of volcaniclastic rocks from the southern volcanic arc provenance and were deposited into the depression and causing the depression to subside.

Geological structures that develop in the LUSI area are faults, anticlines and igneous rock intrusion in the form of andesitic sills. A prominent fault in this area is the Watukosek fault which is an oblique-sinistral strike slip NE-SW trending fault escarpment, while the Siring fault is a dextral strike slip trending NW-SE. The main mud eruption vent appears to be on the top of the Sekar Putih anticline with an East-West trending axis. The geoseismic on figure 3 shows W-NE cross-sectional view through Wunut 2A, Banjarpanji-1 (BJP-1), Tanggulangin-3 (TGA-3) and Porong-1 (PRG-1). Despite the close proximity between BJP-1 and PRG-1 wells, the stratigraphic sucession at each well is very different. Cuttings suggest tight sand on the lower section of the BJP-1 well, and seismically shows a more complicated wrench fault pattern. The thick overpressured shale section between 4400-6200 ft in BJP-1 is a low velocity interval that appears as a large structural dimension. The structural feature in the vicinity of BJP-1 resembles a flower structure suggests the presence of a wrench fault, thus horizontally and oblique sliding moving components. The wrench faults continuously cut through the low velocity intervals which may serve as a conduit for the mudflow up to the surface.

structural geology model in LUSI mud volcano area shown in figure-4 was built using geological and geophysical integrated data that were collected between May 2006 and May 2012. The Watukosek Fault pattern is indicated by the Porong river alignment, lineament direction of Watukosek escarpment, pattern of horizontal displacement from GPS survey, slickenside on paleo and recent sediment. Based on geophysical data interpretation, which include seismic, GPR, VLF, and microgravity, suggest the presence of NE-SW and NW-SE fault patterns. The NW-SE dextral strike slip fault movement from GPS survey data or the Siring Fault movement is clearly visible by the horizontal displacement of railway, water-pipe, fracture orientation. These fault orientation pattern were previously often not apparent due to alluvial cover.

Fractures appeared around LUSI area as a result of fault reactivation which causes loss of cohesion due to both vertical and horizontal movements. These fractures are visible and their displacements were measured and concentrated mainly to the East of the main eruption (Renokenongo village), around the main vent and to the West (Siring Barat village), with displacements of varying degree and magnitude. The fractures follow the sinistral Watukosek fault with NE – SW trend. Juxtaposed with the Watukosek fault reactivation, is the dextral Siring fault movement as second order NW-SE strike-slip movement.

Based on strain stress ellipsoid model by Harding 1974 and considering to the direction of anticline axis, trend and position of the fault, the postulated compressional force is North–South.

Slickenside found in Watukosek escarpment indicates that fault in this area has been reactivated and repeated at the fault zone. This fault is contigous to the LUSI eruption crater. Existence of vertical and horizontal movement and faults that have reached the surface expressed by rock layer at the surface is indicated from identified fractures, GPS survey, GPR, InSAR, VLF, and microgravity survey conducted at LUSI.

geological condition in the area is evidenced by continous topographical changes along the active fault zones, in particular Watukosek and Siring fault zones. Examples of topographic features are the drainage displaced on Porong and Alo rivers, mud retaining wall displaced, slickenside on recent sediment, up-lifted block at NE area of LUSI, sagging or higher rate of subsidence in the Western part of LUSI; folding, tear fault and subsequent thrusting that is visible in the North side of the crater. All of these geological features occurred as a consequence of LUSI mud eruption, with the exception of Porong and Alo rivers' bending which occurred in the past.

GEOTHERMAL POTENTIAL

The temperature at the surface on LUSI is 100 C. Natural heat within the earth is geothermal energy. Reliable power is generated from underground water which seeps below on LUSI location is feasible to develop as geothermal energy. Some rock fragmen in LUSI also shown material come from upper mantle or near by volcanic system. They are metasediment rock and little metamorphic rock.

CONCLUSIONS

There are two active faults that crosses LUSI area which influence the geological structures. These are the oblique-sinistral strike slip NE-SW trending Watukosek fault, and the dextral strike slip with NW-SE trending Siring fault.

The geological phenomena as well as others occurring in the area such as the appearance of fractures, uplift and subsidence, folding and thrusting, horizontal displacement is due to the reactivation of existing faults in this area. Continous topographical changes along the active fault zone is evident as result of the birth of a new mud volcano at the top of Sekar Putih anticline. LUSI is located at the intersection of the Watukosek and Siring faults.

The interpreted structural geology model can be applied for geohazard study, and used as one of the supporting data for disaster area determination. The model suggest some areas may experience more severe damage due to mud flow and fault reactivation that occurs in LUSI and its surrounding area.

Reliable power is generated from underground water which seeps below on LUSI location is feasible to develop as geothermal energy.

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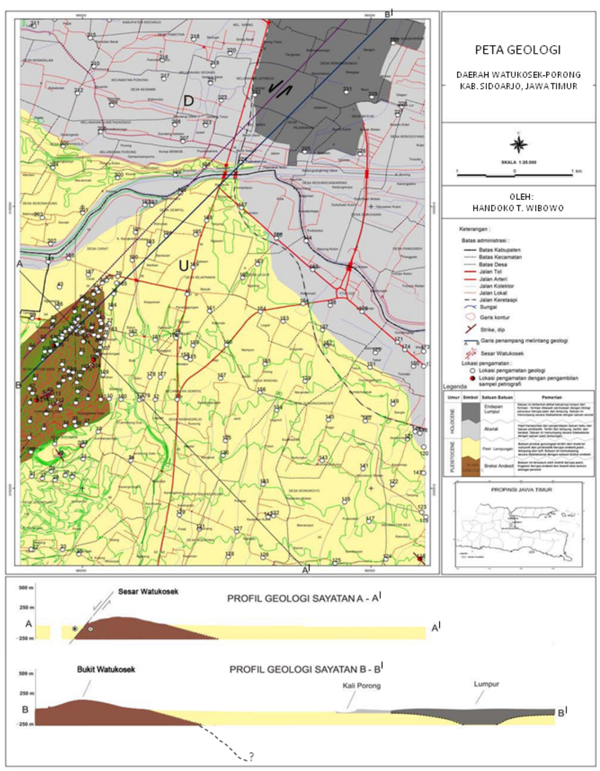

Figure 1. Geological map of Watukosek-Porong and its surrounding. Dark-grey color show the area of LUSI MV.

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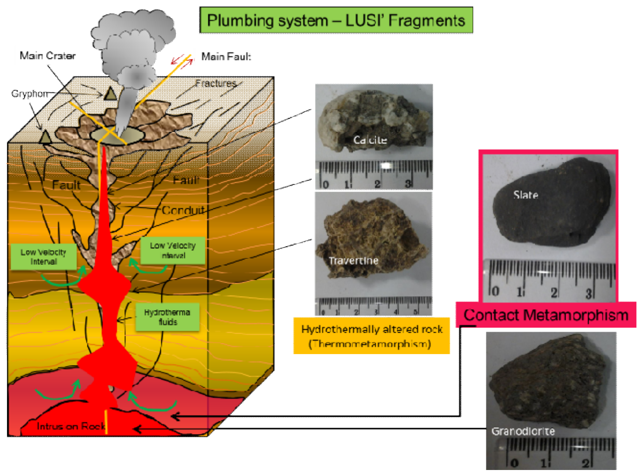

Figure 2. Plumbing Syatem at LUSI MV

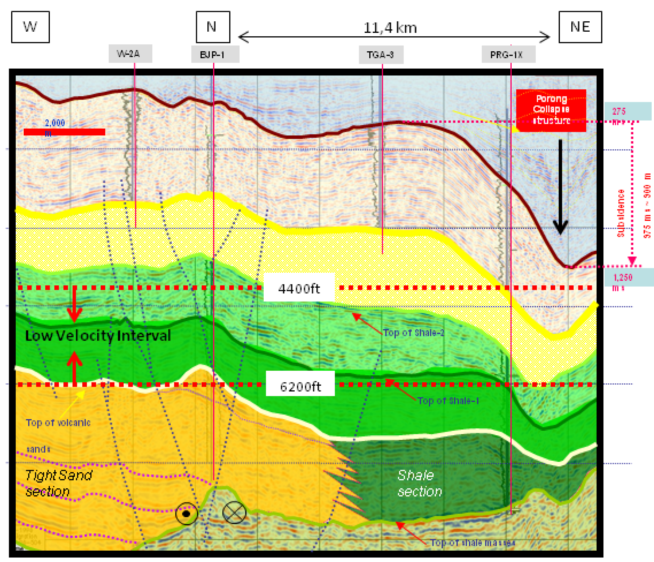

Figure 3. Seismic section of Wunut 2A - LUSI / BJP-1 – TGA-3 – PRG-1 – Porong collapse structure. The multiple faults (wrench fault) near the BJP-1 well (200 m from LUSI) may have been reactivated and served as conduit for the mud eruptions and escaping gas, hence the appearance of gas bubbles along fault lines.

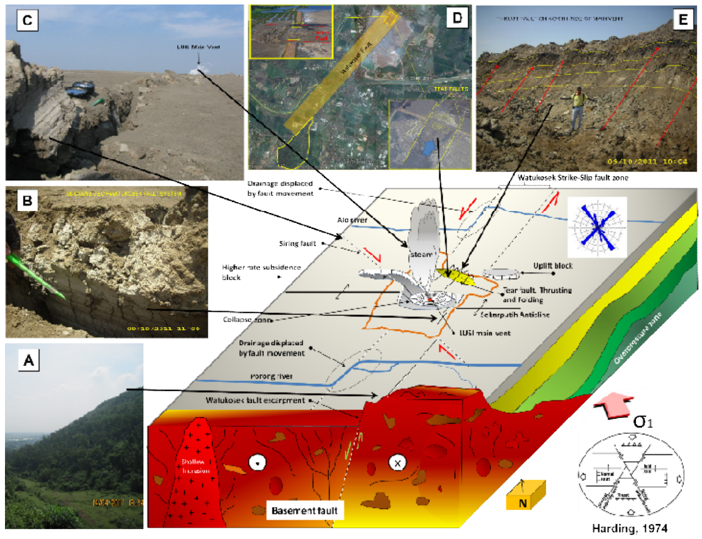

Figure 4.The structural geology model at LUSI MV area. Horizontal displacement measured by GPS survey from June 2006 - March 2007 indicate the major trends are NW-SE and NE-SW as seen in the rose diagram. (A) Watukosek fault escarpment
(B) The slickenside on recent sediment at LUSI MV area with trending NE-SW (C) The slickenside on recent sediment with trending NW-SE that intercept main vent (D) Tear fault in watukosek fault zone with trending NE-SW (E) Thrust fault at north side of main vent

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