The evolution of Sidoarjo hot mudflow (Lusi), Indonesia

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Submission date: 08-Aug-2019 03:28PM (UTC+0700)
Submission ID: 1158565911
File name: P-Wibowo_2018_IOP_Conf._Ser.__Earth_Environ._Sci._212_012050.pdf (1.82M)
Word count: 4580
Character count: 25005

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To cite this article: H T Wibowo *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **212** 012050

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The evolution of Sidoarjo hot mudflow (Lusi), Indonesia

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Abstract: A spectacular hot mudflow in Sidoarjo on May 29, 2006 seized the attention of many people ranging from the general public, government, to experts related from within the local and abroad. Sidoarjo hot mudflow until now still flowing and this geological evidence has not shown any signs of stopping in the near future and causing a great impact on the surrounding environment and socio-economic life of the community as well as raising other speculation against to this geological evidence.
The regional geology of hot mud discharge areas in between the edge of a volcanic arc and back arc basin. This event shows the discharge of material from subsurface layer containing a higher pressure clay from hydrostatic pressure (over pressure shale), very plastic and possibly even in mobile (hydrodynamic) conditions. It is very common in the ellisional basin called mud volcano, although there are differences in the characteristics of LUSI with other mud volcanoes, which are temperature about 100 °C on the surface with a discharge of 150,000 m3 / day. For nearly 12 (twelve) years of flowing, observation activities and measurement of characteristics and behavior continue to be convergence with geological, geochemical, geophysical and geodetic approaches.
The results of the fluid geochemical analysis show that LUSI has already related to geothermal phenomena [16,18]. The result of geological structure analysis shows the existence of piercement structure crossing through the center of eruption while the geodesy analysis using InSAR indicates there are some areas that subsidence and some are uplifted [1] . Based on the results of various approaches and a comprehensive analysis shows that the hot mudflow Sidoarjo has evolved for characteristics, the ratio of the enlarged water, the constant temperature around 100 °C that show to the of volcano signature or it is making of the Neovolcanism.

1. Introduction

The LUSI hot mudflow or LUSI mud volcano is located about 12 km northeast of Penanggungan Mountain, in East Siring village, Porong District, Sidoarjo Regency, East Java. LUSI located is in the Southern part or the edge of between volcanic and hydrocarbon prolific on East Java inverted back-arc Basin which was formed during the Oligocene - Early Miocene [24], on the Eastern part of the Kendeng Zone [4]. The Geology of the are a is characterized by the rapid deposition of thick organic rich sediment as part of the Brantas delta, influenced by the extensional tectonic regime [26]. Due to the rapid deposition, shales in the area are undercompacted and overpressured [19]. The geological condition is similar to other areas where mud volcanoes are found such as the Caspian and

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the Black Sea [19,25] 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. Overpressured zones typically are under-compacted sedimentary layers which have lower density than the overlying rock units, and hence have an ability to flow.

A mud volcano also 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).

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 [20] where earthquakes initiating local fluid movements cause fractures that propagate to the surface manifesting with a time delay from the main earthquake. 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.

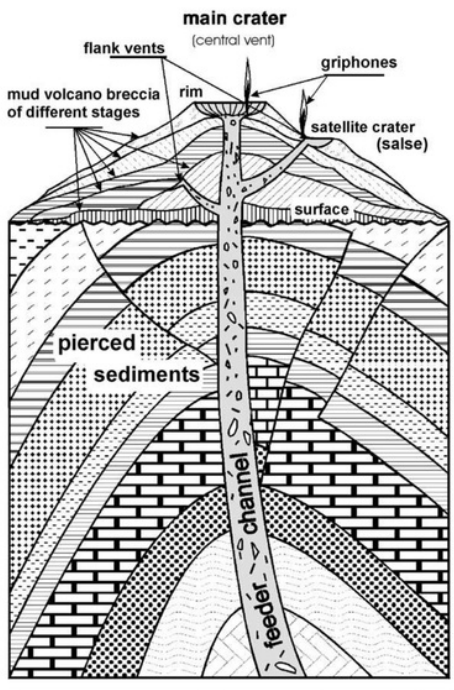

Figure 1. The basic structure and elements of a mud volcano system [7]

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.

2. Background Geology

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 [21]. The East Java geosyncline has thick Tertiary sediments of more than 6000 m [15] with an estimated sedimentation rate of 2480 m/ma in the vicinity of LUSI [14]. 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 [26]. The overpressured sediments were later compressed, become mud diapirs and pierced the overlying sediments in many parts of East Java as mud volcanoes.

The stratigraphy at LUSI consists of (1) alluvial sediments, (2) Pleistocene alternating sandstone and shale of the Pucangan Formation (to about 500 m depth), (3) Pleistocene clay of the Pucangan Formation (to about 1000 m depth), (4) Pleistocene bluish gray clay of the Upper Kalibeng Formation (to 1871 m depth), and (5) Late Pliocene volcaniclastic sand of at least 962 m thickness. The strontium isotope (Sr) of the carbonates shows the absolute age of 16-18 ma Early Miocene, and therefore the carbonates are correlated with the Tuban Formation outcrops found extensively in the western part of East Java basin which show age range from 15.2 ma to 20.8 ma based on analysis of strontium isotopes [22].

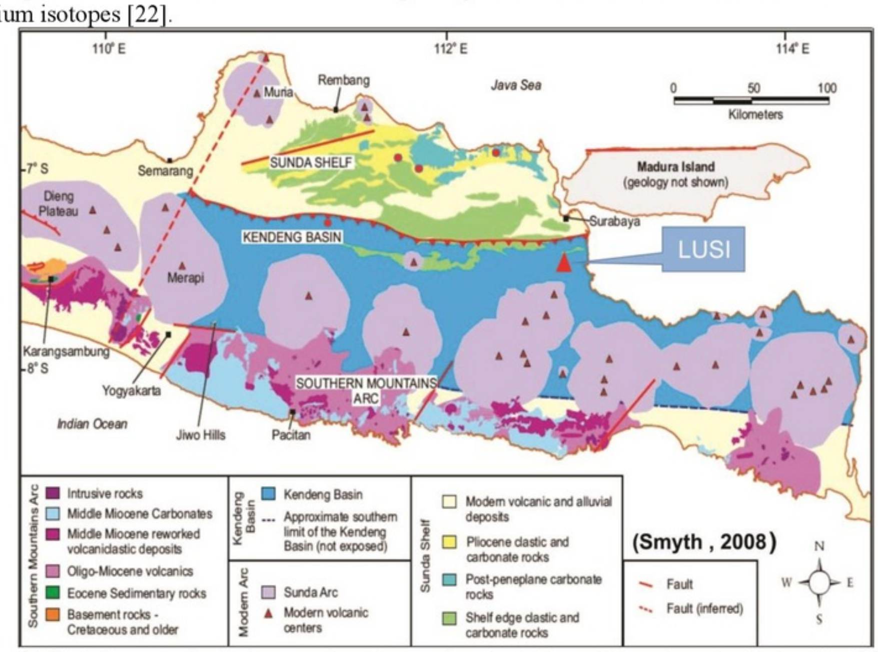

Figure 2. East Java geological map, showing regional stratigraphic and geological units. LUSI hot mudflow appear in the kendeng basin and in the north of the volcanic complex. Several Hotspring (red dot) also shown on northernpart of East Java basin modified from Smyth [23]

3. Methods

3.1 InSAR (Interferometric Synthetic Aperture Radar)

InSAR is a technique to map ground displacement with a high resolution of up to centimeter-level precision [9,17]. InSAR is effective tool to measure the amount of ground deformation caused by earthquake, volcanic activity has been useful for studying land subsidence associated with ground water movements [2,9], mining [3],[6], and geothermal as well as oil exploitation [17]. The amount and pattern of deformation are shown by a range of colors in the spectrum from red to violet. The computed interferograms are interpreted using an inversion method that combines a boundary element method with a Monte-Carlo inversion algorithm [8]. In LUSI, this technique was used to determine the surface deformation due to the mudflow starting from 19 June 2006 (three weeks after the mud eruption) to 19 February 2007. The measurement was done using PALSAR (Phased-Array L-band SAR) onboard the Japanese Earth observation satellite ALOS. Measurement of land subsidence is possible as the L-band microwave is less affected by vegetation [6].

Deguchi et al. [5,6] and [1] performed a study and measured the ground subsidence temporal changes of deformation obtained by applying time-series analysis to the deformation results extracted by InSAR.

From 19 June 2006 to 4 July 2006 the subsidence showed an elliptical pattern, suggesting subsidence around the main vent and west of the main vent. From 4 July 2006 to 19 February 2007, the scale of subsidence and uplift became more significant. Both subsidence and uplift East of the main vent became more pronounced. In contrast to the high rate of mud eruption however, the InSAR results clearly showed that the ground deformation associated with mud eruption decreased after November 2006 (see figure 4).

3.2 Horizontal Displacement from GPS Geodetic

One method to determine the vertical and horizontal movement of the earth's surface is to use GPS geodesy. It can detect lateral and vertical movements up to 0.01 cm accuracy. Geodetic GPS measurements in warp have been started since the burst occurred until now. Geodetic measurements were conducted at the LUSI site to quantify the ongoing deformation processes. The primary data sources were the GPS surveys periodically conducted at monitoring stations to measure vertical and horizontal movements relative to a more stable reference station. Seven GPS survey campaigns were conducted between June 2006 and April 2007. The GPS measurements were conducted at 33 locations using dual- frequency geodetic type receivers over various time intervals. Each measurement lasted from 5 to 7 h. [12]. Areas within a 2–3 km radius of LUSI's main mud eruption vent are experiencing ongoing horizontal and vertical movement aligned to major faults. The horizontal displacements have spatial and temporal variations in magnitude and direction, but generally follows the two major trends, namely in the direction of NE - SW and NW – SE. Rates of horizontal displacement are about 0.5–2 cm/day, while vertical displacements are about 1–4 cm/day, with rate increasing towards the extrusion centre [1].

3.3 Fracture and Shear Mapping

Shear and fracture orientation mapping in the LUSI area was conducted to see the distribution and pattern of deformation in the LUSI area. It is important to see the trend of the model and direction of the fault movement (see figure 7).

3.4 Faulting Mechanical Model

This Moody and Hill model basically divides the geological structure that forms into several orders. If the force of order 1 is strong, it will produce a compression force for order 2 and order 3. But if the force of order 1 is weak, only order 1 will be formed. This model can be applied to areas with homogeneous rocks and geological structures have never happened with pure shear stress.

The stress stress ellipsoid model is a structural analysis model proposed by Harding in 1974. This structural analysis model is used to determine the direction of the compression force forming the structure, both muscular and faulty. This ellipsoid strain stress model can also be estimated in which direction the normal fault and thrust fault can occur and the direction of the fold axis. Interpretation of the direction of the forming force uses the Harding model because this model can be used on heterogeneous rocks with simple shear stress, and there are similarities with the geological structure components found in the study area.

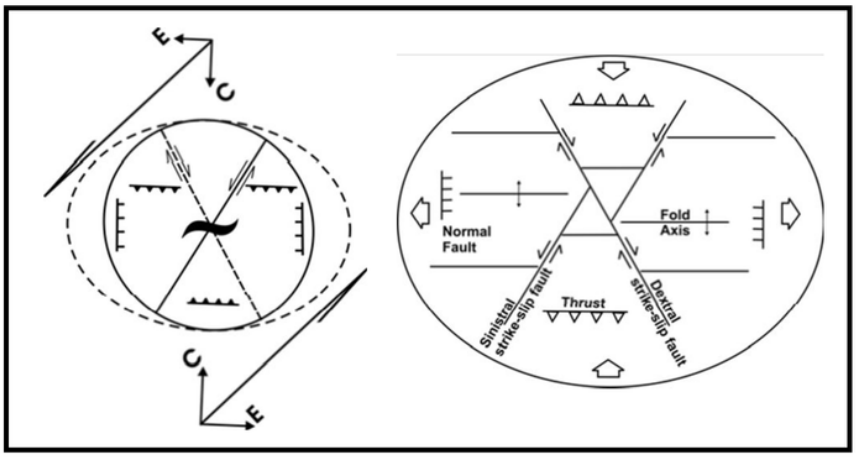

Figure 3. The stress ellipsoid model strain is a structural analysis model proposed by Harding [10], this model is in accordance with geological conditions in the study area where have similarities with the geological structure components found in the study area.

4. Results

The results from the use of InSAR indicate subsidence has occurred in this area. Four different areas of deformation is suggested, these include areas centered around the main eruption vent; areas to the west-northwest of the main vent; areas to the northeast of main vent; and to the southwest of the main vent. Apart from the areas to the west-northwest which is associated with the deformation due to gas production in Wunut gas field, the other 3 deformation areas follow the regional fault pattern, contiguous to the Watukosek NE-SW fault trend.The results also demonstrate the progressive subsidence evolution from time to time during the period of measurement. Subsidence in the main eruption area showed the most rapid subsidence rates. The 8-months measurements period showed ellipsoidal subsidence pattern covering an area of approximately 2 x 3 km2 with a long axis trending NE-SW. Another area to the west-northwest of the main eruption area is also experiencing subsidence. This particular area is within the Wunut gas field which covers approximately 2 X 2.5 km2 with long axis trending NW-SE. This trend corresponds to the regional Siring NW-SE fault trend.

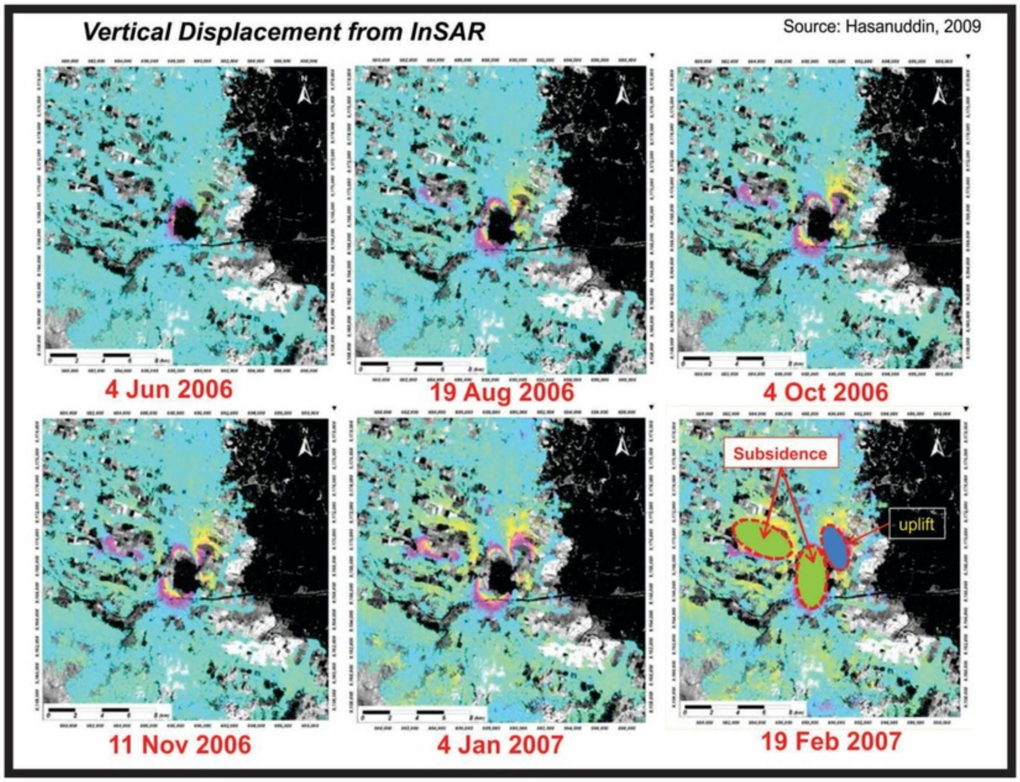

Figure 4. Changes in Insar's data from June 2006 to February 2007, there was a vertical displacement as subsidence and uplift in the LUSI area and showed a decreasing trend [11]

Fractures appeared around LUSI area as a result of loss of cohesion due to ground movement, both vertical and horizontal movements. These fractures were 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 NE – SW trend. Juxtaposed with the Watukosek fault reactivation, is the Siring fault movement that trends NW – SE which has dextral strike slip movement. These fractures were caused by reactivation of faults but their orientation pattern are often not apparent due to thick alluvial cover [13].

GPS geodetic measurement data shows that there are points that are constantly moving and some are only experiencing movement once or twice. Data obtained from GPS measurements every month from June 2006 to March 2007 were compiled and matriculated to obtain horizontal trend/displacement patterns. From the results of compilation and data matriculation, the pattern/trend of horizontal displacement is obtained in the area around the main vent. There are 2 patterns/trends of horizontal displacement direction in this area namely in the direction of NE - SW and NW – SE (see figure 5B)

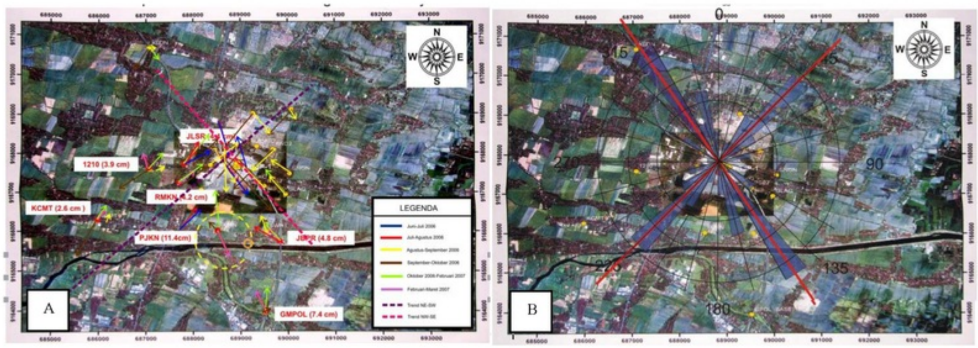

Figure 5. (A) Horizontal Displacement data set from GPS Geodetic on June 2006 to March 2007 (B) Rose set diagram from Horizontal Displacement on June 2006 to March 2007

The results of the interpretation using the Harding model in the study area, shows the direction of the fault forming force is North - South. In the Harding model it can be seen that if there is a compression force north - south it will produce a strike slip (Northeast - Southwest) called Watukosek Fault, and Northwest - Southeast called Siring fault, thrust fault (West - East), normal fault (North - South) and anticline (West - East) see figure 6B.

The overlay result of InSAR measurement and fault kinematics that exist in the area shows a positive correlation between evidence on site and InSAR. Subsidence located to the west of the center of the main vent has a long axis which is directed towards NE - SW which is the direction of the Siring fault, while subsidence located at the center of the main vent has a long axis NE - SW which is the direction of the Watukosek fault. Elipsoidal uplift results from InSAR measurements show that the NNW - SSE long axis is a restraining stepover in offset oblique slip fault from watukosek fault reactivation.

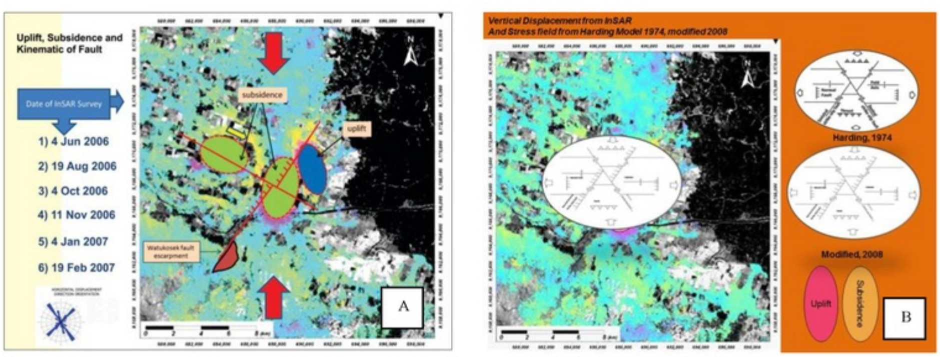

Figure 6. (A)The correlation between the elipsoidal long axis correlation of the InSAR measurement with the watukosek fault direction and the siring fault. Elipsoidal progressive evolution uplift based on the NNW-SSE long axis directional measurement is the restructuring stepover in offset oblique strike slip fault from the fault reactor reactivity.(B) Appearance of Subsidence and Uplift in InSAR which proves the reactivity of Fault Siring and Watukosek Fault overlaid with ellipsoid stress.

5. Discussions

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 [13].

The structural geology model in LUSI mud volcano area shown in figure was built using geological and geophysical integrated data that were collected between May 2006 until now. 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. 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. The other side, at the southern part or in watukosek hill we can find sill intrusion appear on the surface.

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 antitetic fault with NW-SE strike-slip movement.

Based on strain stress ellipsoid model by Harding [10] 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, InSAR, conducted at LUSI.

Dynamic 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.

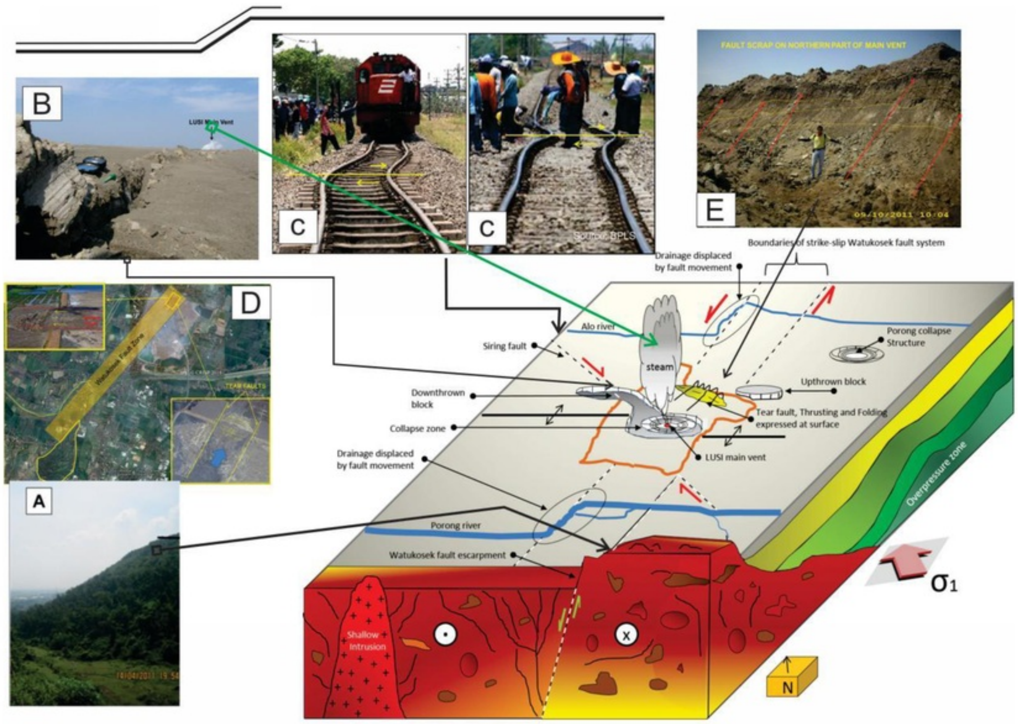

Figure 7. The structural geology model at LUSI MV area. Horizontal displacement measured by GPS survey from June 2006 - March 2007 indicate the major trends are NW-SE and NE-SW as seen in the rose diagram. (A) Watukosek fault escarpment (B) The slickenside on recent sediment at LUSI MV area with trending NE-SW (C) Railway bended at westernpart of LUSI with trending NW-SE (D) Tear fault in watukosek fault zone with trending NE-SW (E) Thrust fault at north side of main vent

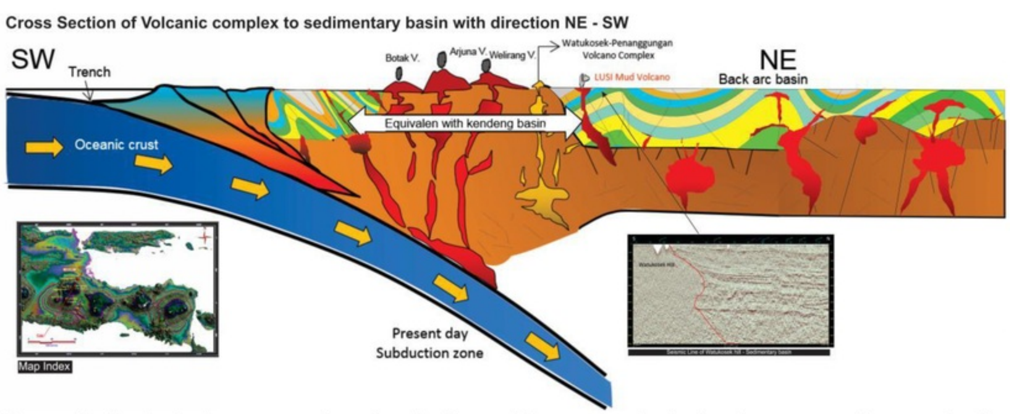

Figure 8. Geological cross section that in line with watukosek faults that across fore arc basin-volcanic complex and back arc basins. At the incision interpreted there are potential heat sources that are still stored and some have appeared as hydrothermal manifestations in the back arc basin or in the kendeng and rembang zone

6. Conclusions

Sidoarjo hot mudflow which has been ejected for more a decade and has not yet indicated that it will stop will certainly grab the attention of the geoscientists. At the beginning of the incident, geoscientist considered the occurrence of this hot mudflow as a phenomenon of the birth of mud volcanoes, but over time the collected data and information showed that this phenomenon is a geysers. Geysers are react from post-magmatism that reappear because there is pressure up from below and out through the weak plane in the form of the fault. The fault that was identified was the watukosek fault which was directed towards the northeast-southwest and the antitetic fault was a siring fault that crossing the watukosek fault with the NW-SE direction. Based on data and evidence for more than a decade, this phenomenon has begun to evolution and shifting from the typical mud volcano become to atypical mud volcano and has led to the signature volcanic and the implication is to open up opportunities to be symptoms of Neovolcanism in the Kendeng and Rembang zones which appeared hydrothermal manifestations (sedimentary hosted hydrothermal system) in several places in both zones.

References

[1] Abidin, H.Z., Davies, R.J., Kusuma, M.A., Andreas, H., Deguchi, T., 2008., Subsidence and uplift of Sidoarjo (East Java) due to the eruption of the LUSI mud volcano (2006 present). Environmental Geology doi:10.1007/s00254-008-1363-4.

[2] Amelung, F., Galloway, D.L., Bell, J.W., Zebker, H.A., Laczniak, R.J., 1999. Sensing the ups and downs of Las Vegas: InSAR reveals structural control of land subsidence and aquifer-system deformation. Geology 27 (6), 483–486.

[3] Carnec, C. and Delacourt, C., 2000. Three years of mining subsidence monitored by SAR interferometry, near Gardanne, France. *Journal of Applied Geophysics*, *43*(1), pp.43-54.

[4] De Genevraye, P., Samuel, L., 1972. Geology of the Kendeng zone (Central and East Java). In: Proceedings of the Indonesian Petroleum Association, 1st Annual Convention,pp. 17–30.

[5] Deguchi, T., Maruyama, Y., Kato, M., 2007b. Measurement of long-term deformation by

[6] Deguchi, T., Maruyama, Y., Kato, M., Kobayashi, C., 2007a. Surface displacement around mud volcano, East Java captured by Insar using Palsar data. In: Proceedings of the 28th Asian Conference on Remote Sensing.

[7] Dimitrov, L.I., 2002. Mud volcanoes: the most important pathway for degassing deeply buried sediments. Earth Science Reviews 59 (1–4), 49–76.

[8] Fukushima, Y., Cayol, V., Durand, P., 2005. Finding realistic dike models frominterferometric synthetic aperture radar data: the February 2000 eruption at Piton de la Fournaise. Journal of Geophysical Research 110 B03206. doi:10.1029/2004JB003268.

[9] Hanssen, R.F., 2001. Radar Interferometry – Data Interpretation and Error Analysis. Kluwer Academic Publishers, Dordrecht, The Netherlands.

[10] Harding, T.P., 1974. Petroleum traps associated with wrench faults. *AAPG bulletin*, *58*(7), pp.1290-1304.

[11] InSAR using ALOS/PALSAR data. In: Presented at FRINGE 2007 workshop, November 2007, Frascati, Italy. Workshop presentation available from: http://earth.esa.int/workshops/fringe07/presentations.html/ Workshop proceedings are in press.

[12] Istadi, B., Pramono, G.H., Sumintadireja, P., Alam, S. Simulation on growth and potential Geohazard of East Java Mud Volcano, Indonesia. Marine & Petroleum Geology, Mud volcano special issue, doi: 10.1016/j.marpetgeo.2009.03.006.Java, Indonesia. In: 23rd Annual Convention, vol. I. IPA, pp. 101–111.

[13] Istadi, B.P., Wibowo, H.T., Sunardi, E., Hadi, S. and Sawolo, N., 2012. Mud volcano and its evolution. In *Earth sciences*. InTech.

[14] Kadar, A.P., Kadar, D., Aziz, F., 2007. Pleistocene stratigraphy of Banjarpanji#1 well and the surrounding area. In: Proceedings of the International Geological Workshop on Sidoarjo Mud Volcano, Jakarta, IAGI-BPPT-LIPI, February 20–21, 2007. Indonesia Agency for the Assessment and Application of Technology, Jakarta.
[15] Koesoemadinata, R.P., 1980. Geologi Minyak dan Gas Bumi. 2 jilid, ed ke-2. Penerbit ITB, Bandung.
[16] Malvoisin, B., Mazzini, A. and Miller, S.A., 2018. Deep hydrothermal activity driving the Lusi mud eruption. *Earth and Planetary Science Letters*, *497*, pp.42-49.
[17] Massonnet, D., Feigl, K.L., 1998. Radar interferometry and its application to changes in the . Earth's surface. Review of Geophysics 36, 441–00.
[18] Mazzini, A., Nermoen, A., Krotkiewski, M., Podladchikov, Y.Y., Planke, S., Svensen, H., 2009. Strike-slip faulting as a trigger mechanism for overpressure release through
[19] Mazzini, A., Svensen, H., Akhmanov, G.G., Aloisi, G. Planke, S., Malthe-Serenssen, A and Istadi. B., 2007, Trigering and dynamic evolution of LUSI mud volcano, Indonesia: Earth and Planetary Sciences Letters, v. 261, p. 375-388.
[20] Mellors, R., Kilb, D., Aliyev, A., Glasanov, A. and Yetirmishli, G. (2007): Correlations between earthquakes and large mud volcano eruptions. Journal of Geophysical Research, 112, doi:10.1029/2006JB004489.
[21] Satyana, A.H. and Armandita, C., 2004, Deep-Water play of Java, Indonesia : regional evaluation on opportunities and risks, Proccedings International Geoscience Conference of Deepwater and Frontier Exploration in Asia and Australasia, Indonesian Petroleum Association (IPA) and American Association of Petroleum Geologists (AAPG), Jakarta, p. 293-320.
[22] Sharaf, E.F., BouDagher-Fadel, M.K., Simo, J.A. (Toni) and Caroll, A.R., 2005, Biostratigraphy and strontium isotope dating of Oligocene-Miocene strata, East java, Indonesia., Stratigraphy, vol. 2, no. 3, pp. 1-19, text figure 1-4, tables 1, plate 1-5.
[23] Smyth, H.R., Hall, R. and Nichols, G.J., 2008. Cenozoic volcanic arc history of East Java, Indonesia: the stratigraphic record of eruptions on an active continental margin. *SPECIAL PAPERS-GEOLOGICAL SOCIETY OF AMERICA*, *436*, p.199.
[24] Sribudiyani, Nanang Muchsin, Rudy Ryacudu, Triwidiyo Kunto, Puji Astono, Indra Prasetya, Benyamin Sapiie, Sukendar Asikin, Agus H. Harsolumakso, and Ivan Yulianto. "The collision of the East Java Microplate and its implication for hydrocarbon occurrences in the East Java Basin." (2003): 1-12.
[25] Tingay, M.R.P., Heidbach, O., Davies, R., Swarbrick, R., 2008. Triggering of the LUSI Mud eruption: Earthquake versus drilling initiation. Geology, 36(8), pp.639-642..
[26] Willumsen, P., Schiller, D.M., 1994. High quality volcaniclastic sandstone reservoirs in East

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