

Roles of Mud Volcanoes Eruptions in the Decline of the Jenggala and Majapahit Empires, East Java, Indonesia: Constraints from Historical Chronicles, Folklore, and Geological Analysis of the Brantas Delta-Kendeng Depression

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ABSTRACT

The Brantas Delta and its underlying Kendeng Zone, where Jenggala and Majapahit Empires existed from 11th to 16th AD Century, show an elisional system causing the occurrences of mud diapirs and mud volcanoes. The effectiveness of the Kendeng elisional system shown by the presence of LUSI mud volcano, which has been erupting since May 2006. This paper argues that eruptions of mud volcanoes also took place in the Jenggala-Majapahit period and they had affected the decline of these two empires. This consideration is based on: historical chronicles during the Majapahit time, local folklore composed during the Jenggala time, geologic analysis of the Jenggala-Majapahit area, and field analogue to LUSI mud volcano (Satyana, 2007).

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Introduction

Jenggala and Majapahit were two Hindu empires existed in the 11th to early 16th AD centuries and located at the Brantas Delta, East Java, Indonesia (Figure 1). The rise, growth, and decline of these two empires more or less related to the geological processes taking place in the Brantas Delta (Nash, 1931; Daldjoeni, 1992; Satyana, 2007). The Jenggala Empire was established in 1042 AD, lasted for almost 75 years, fell in 1116 AD, and annexed by the Kediri Empire. The Majapahit Empire started in 1293 AD, grew successfully for the first one hundred years, and fell in 1478 AD. Majapahit Empire became the subordinate to the Islamic Demak Sultanate, and ended in 1518 AD.

Based on interpretations of the historical chronicles of the "Kitab Pararaton"- The Book of Kings (1613 AD), "Serat Kanda" – Letter of Story (early 18th AD Century), and "Babad Tanah Jawi" – Chronicles of Java Land (early 18th AD Century), a folklore developing in the Jenggala and Kediri period, geological analysis of the area where Jenggala and Majapahit were situated, and an analogue to the present "LUSI" (abbreviated form of "Lumpur Sidoarjo" - Sidoarjo Mud); Satyana (2007) argued that natural disasters in the form of mud volcanoes eruptions played major role in decline of Jenggala and Majapahit Empires before they were annexed by other competing empires.

This article summarized the arguments of the author (published firstly by Satyana, 2007), discussing the constraints from historical chronicles, folklore, and geological analyses leading to conclusions that eruptions of mud volcanoes played significant roles for the decline of the Jenggala and Majapahit Empires.

Brantas Delta: Birth Place of Empires and Its Geology

The Brantas Delta, East Java, is a delta located to the south and southwest of Surabaya. It has been formed by the deposition of sediments brought by the Brantas, Porong, and Mas Rivers (Figure 1). The Brantas River is the biggest and the longest river in East Java. It has its source from the volcanic area in the middle of East Java, flowing through valleys among the volcanic terrains and forming the delta approaches its mouth. The delta sedimentation continued to Madura Strait. To the south of the delta there are magmatic volcanic complex of Penanggungan, Arjuno, Welirang, and Anjasmoro.

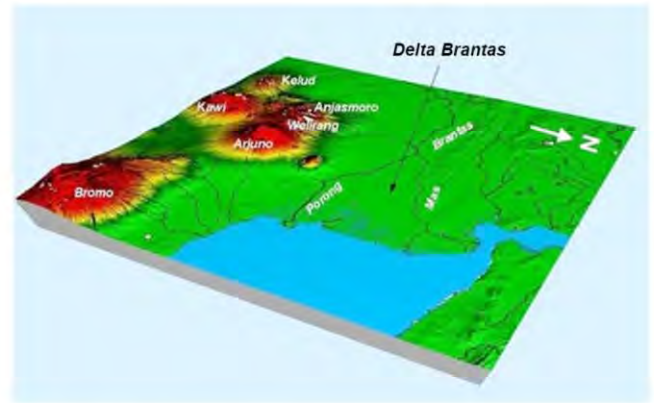


Figure 1. Delta Brantas in East Java where empires/kingdoms were located in history. Geologically, the delta sits overlying the Kendeng Depression where most of overpressured structures and mud volcanoes have been situated.

The Brantas Delta has been populated since the Early Pleistocene. One skull of early human (hominid) later named as *Homo modjokertensis* was found in 1936 within Pucangan volcanic-clastic beds in Perning area to the north of Mojokerto.

The site is close to the Mas River, one of the rivers forming the Brantas Delta. Because of its land fertility, political situation, the Brantas Delta has become birthplace of Hindu empires in East Java (the Empires of Medang, Kahuripan, Jenggala, and Majapahit from 10th to 16th AD centuries) (Lombard, 2005). These empires built their capitals in the Brantas Delta.

Geologically, Brantas Delta is an active area. The delta is sitting on top of mobile zone called the Kendeng Depression, an axial Java trough (Figure 2). The Kendeng Depression is an ideal "elisional" basin that consist of very thick Plio-Pleistocene volcanic-clastic and siliciclastic sediments sourcing from the nearby highs that had been deposited rapidly, less compacted, and overpressured (Satyana, 2007).

High geothermal gradient due to the depression in Miocene to Recent volcanic arcs has added the mobility of the sediments. In addition, the sediments have also been compressed due to the frontal subduction of Indian oceanic plate to the south of Java occurring since late Paleogene.

These elisional conditions have mobilized materials in the Kendeng Depression forming diapirs, anticlinorium, and mud volcanoes. Diapirs and anticlinorium, some of which breach to surface bringing mud volcanoes, are commonly found in the Delta Brantas.

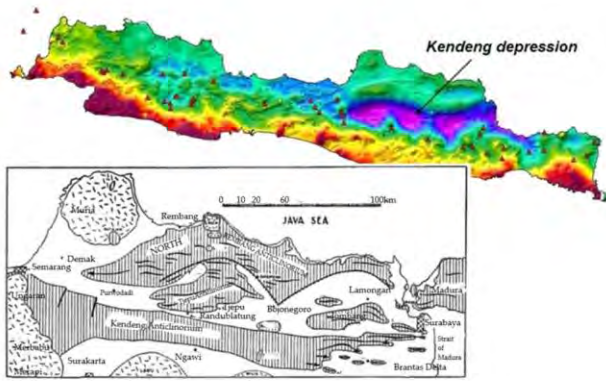


Figure 2. Kendeng Depression, a very deep basin in the middle eastern part of Java Island which continues into the Madura Strait. Most of the Pliocene sediments were rapidly deposited into the basin, overpressured, and compressed forming some surface anticlines in the Brantas area like on the map below (van Bemmelen, 1949). The sedimentary and structural conditions like that occurred in the Kendeng Depression area is called “elisional” basin.

Jenggala and Majapahit Empires: Rise and Fall

Jenggala and Majapahit were the two empires located in the Brantas Delta. Beforehand, there were Medang (928-1019 AD) and Kahuripan (1019-1042 AD) (Soeroto, 1954). Mpu Sindok, Teguh Dharmawangsa, and Erlangga were the famous emperor of the Medang and Kahuripan Empires. In 11th AD, Erlangga ended his rule over Kahuripan and divided the Kahuripan into two kingdoms: Jenggala and Kediri (Panjalu or Daha). The Kediri was located at the upper Brantas River at present Kediri area, whereas the Jenggala was located at the lower Brantas River, at the Brantas Delta area, near to present Sidoarjo area (Figure 3). There have not been much historical records of Jenggala, the Kingdom was annexed by its relative Kediri in 1116 AD (Figure 4).

After 177 years of absence, the Brantas Delta has regained its status to become the center of the kingdom when King Raden Wijaya built its kingdom called the Majapahit Empire in the last of 13th AD century (1293 AD) (Figure 5). Tarik, a village to the north of the Porong River was built to become the center of the Empire. During the rule of King Hayam Wuruk (1350-1389 AD), the capital city of the Empire was moved to Trowulan, to the south of Mojokerto or at the beginning of the Brantas Delta.

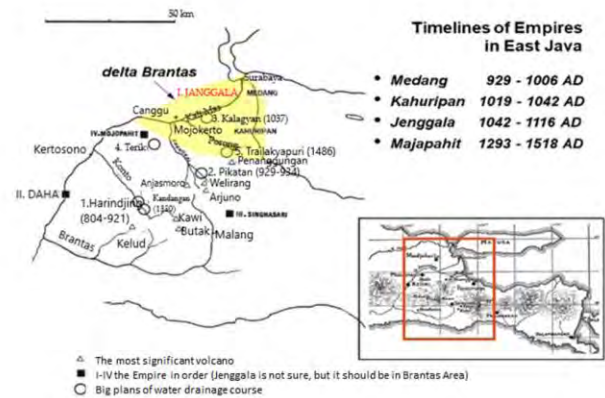


Figure 3. The existence and periods of empires in East Java. The empires of Medang, Kahuripan, and Jenggala centered on the delta, and Majapahit was close to the delta. The map is modified after Lombard (2005), inset map is from Mansur, 1956).

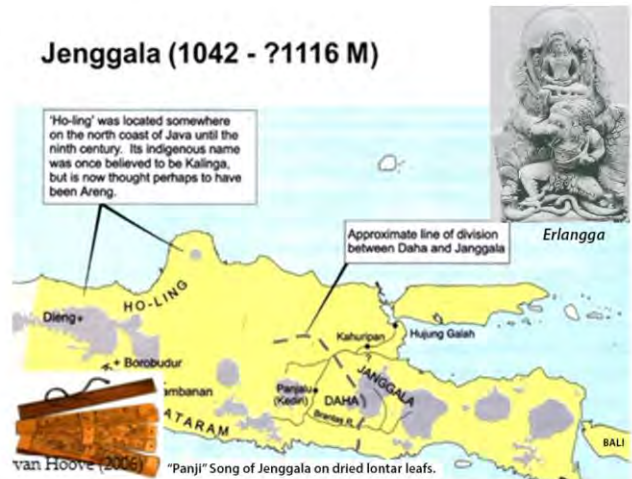


Figure 4. The empires of Jenggala and Panjalu after division of Kahuripan empire by King Erlangga. Inset on lower left is a picture of dried lontar leaves containing Panji story/song in the time of Jenggala. One of the Panji story is “Timun Mas”, discussed in this study. Map is from Cribb (2000).

Starting with the fall of the Majapahit Empire in 1520 AD, the Brantas Delta has no longer become the center of kingdom by later Islamic empires. Islamic kingdom in the later centuries developed in northern Central Java (Demak area) and southern Central Java (Surakarta-Yogyakarta areas).

The Majapahit was the biggest and most successful empire in the Indonesian history. Under rule of King Hayam Wuruk (1350-1389 AD) and Prime Minister Gajah Mada (1313-1364 AD), Majapahit attained its golden era conquering many territories in Indonesia and neighboring countries. No other kingdom in

Indonesian history with the same area of territory as big as Majapahit's territory. According to historical chronicle of Nagarakretagama song of XIII-XV (Muljana, 2005), the conquered territories of Majapahit is as wide as present Indonesian territory including several territories in Southeast Asia. Majapahit has been referred to as good pattern for later kingdoms including the Republic of Indonesia.



Figure 5. The center of empire of Majapahit in East Java. Canggu was a harbor of the kingdom in the starting point of the Delta Brantas. Quaternary geology of the delta once affected the effectivity of Canggu as a harbor for the kingdom. Map is from Cribb (2000).

The decline and fall of the Jenggala have been related to Kediri annexation. The decline and fall of the Majapahit have been related to several factors : (1) power struggle among the heirs of Majapahit, (2) internal weakening by Majapahit kings and heirs who supported Islamic Demak sultanate, and (3) annexation by Demak sultanate. "Sirna Ilang Krtaning Bhumi" (the end of prosperity on Earth) was a famous historical words related to fall of Majapahit.

However, historical records during the Majapahit time unexposed so far to many people, folklore developing in the Jenggala time, recent massive disaster as we see on LUSI occurring in the Brantas Delta, the occurrences of many old mud volcanoes in the Brantas Delta, geological analyses of the elisional Kendeng Depression, and geodynamics of the Brantas Delta show the possibility that massive mud volcanoes eruptions ever occurred during the Jenggala and Majapahit time. This occurrence inferred to be significant cause on the decline of Majapahit and Jenggala Empires.

Geology remains constant, what happens

today in LUSI could also happen in Jenggala and Majapahit time as historical chronicles tell – the present is the key to the past.

The following chapters discuss the Quaternary geological disasters during Jenggala and Majapahit time that may decline the empires, recorded on historical chronicles or folklore (Satyana, 2007).

Geological Disasters in the "Kitab Pararaton": "Banyu Pindah" 1256 Çaka and "Pagunung Anyar" 1296 Çaka

"Kitab Pararaton" (The Book of Kings) is a historical chronicle written in old Javanese script telling about the kings ruling the Singhasari and Majapahit Kingdoms (Brandes, 1897). The Singhasari Kingdom (1222-1292 AD) was a successor of Kediri and the predecessor of Majapahit. Raden Wijaya, the founder of Majapahit was a son in law of Kartanegara, the last emperor of Singhasari. According to Muljana (1968), Pararaton was written in 1535 Çaka (1613 AD). Most of historians could acknowledge the historical value of Pararaton. The stories it tells can be compared to similar stories of other historical records like Chinese notes.

Interestingly, Pararaton recorded two events that their meanings can be related to geological disasters during the Majapahit time (Daldjoeni, 1992; Komandoko, 2008):

- a disaster called "Banyu Pindah" (1256 Çaka or 1334 AD).
- a disaster called "Pagunung Anyar" (1296 Çaka or 1374 AD).

"Banyu Pindah" is diversion of water, and "Pagunung Anyar" is a new volcano.

We will understand what is meant by a disaster called "Banyu Pindah" if we refer to plaque of ancient inscription made by Erlangga in 959 Çaka (1037 AD) called the Kelagyan Plaque.

Presently, Kelagyan is a village named Kelagen to the north of the Porong River (Figure 6). The Kelagyan Plaque discussed the building of big dam in Waringin Pitu area by Erlangga to re-route the flow of the Brantas River which had changed its direction of flow suddenly in one night (this was a kind of move of water or "banyu pindah"). How did the flow of the Brantas River change its route in just one night? The answer is found in Nash (1931) who investigated the hydrogeology of the Brantas Delta. Nash (1931) found seven anticlines trending west-east deforming the Brantas Delta. These anticlines are still active today and deforming the Brantas Delta sediments.

Movement of these anticlines will affect all surface elements including the Brantas River. It was the peak movement of one of these anticlines that diverted the flow of the Brantas River in Erlangga's time. These movements repeated for several times causing the diversion of overlying stream or river. One of the diversion occurred in the Majapahit period in 1334 AD during the rule of Empress Tribhuwana and it was recorded in the Pararaton (Komandoko, 2008).

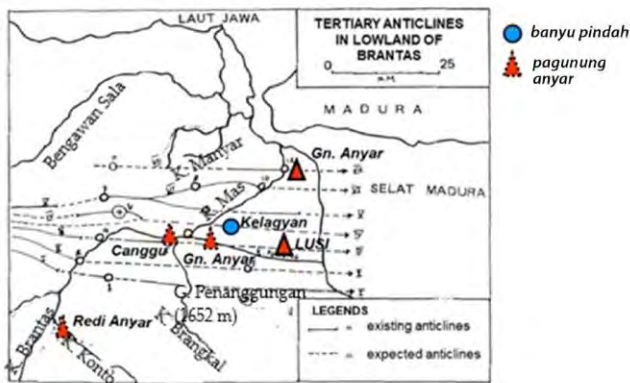


Figure 6. The belts of Tertiary anticlines in the Delta Brantas area and Kendeng Depression. Existence of *banyu pindah* (diversion of water/river) and *pagunungan anyar* (mud volcano) are marked based on historical chronicles and interpretation of other sources (see Satyana, 2007 for detailed explanation). East-west trending anticlines show north-south far field stress affecting diapiric structures and eruption of mud volcanoes within elisional basin of Kendeng Depression. Map is modified after Nash (1931) and Daldjoeni (1992).

The disaster of "Pagunungan Anyar" occurred in 1374 AD when Hayam Wuruk ruled the Majapahit. The name of "Gunung Anyar" is commonly found in the Brantas Delta area and they are related to the sites of mud volcano eruption since a mud volcano called the Gunung Anyar is located close to the Juanda Airport to the south of Surabaya. Due to this reason, the "Pagunungan Anyar" disaster recorded in the Pararaton should be a mud volcano eruption.

Field investigation by Nash (1931) in areas where Majapahit established, found the evidence of deformation that may relate to mud volcanism. The deformation started in Tunggorono hill complex located to the south of present Jombang, continued northeastwards to Jombatan and Segunung.

The deformation then progressed to Majapahit's port called Canggu close to present Mojokerto, diverting eastwards to Bangsal (located 25 km to the west of present LUSI).

Presently, spanning for 25kms from Tunggorono to Bangsal area are found Gunung Anyar Village, Denanyar Village, and Redi Anyar Village (Figure 7). All of these names are related to new volcano. New volcano is referred to mud volcano since built immediately as mud erupts.

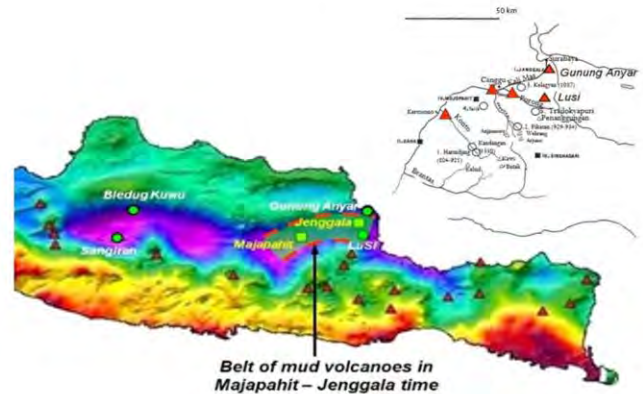


Figure 7. Kendeng Depression (purple in color), an elisional basin where overpressured structures and mud volcanoes commonly occur, and belt of mud volcanoes in the time of Jenggala and Majapahit, red triangles are interpreted locations of historical mud volcanoes based on historical chronicles (Satyana, 2007).

Should all of the eruptions of mud volcanoes from Tunggorono to Bangsal areas were as massive as LUSI eruption, it is considered that the eruptions were disturbing very much in Majapahit time. When Majapahit's port Canggu was deformed, the port ceased its function and this might have decline the maritime business of Majapahit.

Chronowords of Majapahit Fall: "Sirna Ilang Krtaning Bhumi" 1400 Çaka

According to de Graaf (1949), the fall of Majapahit occurred in 1400 Çaka or 1478 AD as recorded in the history of Java. The 1400 Çaka was remembered by chronowords (string of words denoting both time and event) of "Sirna Ilang Krtaning Bhumi" reversed coded as "0041" meaning the year of 1400 Çaka (recorded in historical chronicles of "Serat Kanda" and "Babad Tanah Jawi" (written in early 18th AD century).

Chronowords are composed in such a way to figure out both numerical year and the event occurring on the year. The chronowords of "Sirna Ilang Krtaning Bhumi" was composed to figure out the fall of Majapahit Empire on the year of 1400 Çaka (and each word in the chronowords has numerical code). "Sirna Ilang Krtaning Bhumi" means "the end of prosperity on Earth"

(due to the fall of Majapahit Empire). The words in the old Javanese chronowords are old Javanese or Sanskrit words.

It is interesting to re-interpret the word of "krta" in the chronowords. The word of "krta" or "kerta" is a Sanskrit word with several meanings (Wojowasito, 1980) : 1) "it is already done, completed, good, safe, prosperous, result, service 2) a dice. "Ni/ning" is a possessive particle. Based on this, the chronowords "sirna ilang krtaning bhumi" could have meanings of : (1) "the end of things by completeness of Earth's work or (2) "the end of prosperity on Earth". The meaning number (1) seems related to a geological disaster.

The meaning number (1) may associate with other event recorded in Majapahit chronicle known as the "Guntur Pawatugunung" discussed below.

"Guntur Pawatugunung" 1403 Çaka : Volcanic Eruption

"Guntur Pawatugunung" was an event according Ricklefs (1999) occurred in 1403 Çaka (1481 AD). The event was commonly interpreted as volcanic eruption (Berg, 1962; Purwanto, 1983; Daldjoeni, 1992; Ricklefs, 1999). Berg (1962) interpreted that the event was a natural mark of the fall of Majapahit and the rise of the Demak Sultanate. Javanese people believed that significant politic succession or change will be marked by natural phenomena. "Guntur Pawatugunung" literally means thunder sound of volcanic stone, meaning a volcanic eruption.

The occurrences of "sirna ilang krtaning bhumi" (1400 Çaka) and "guntur pawatugunung" (1403 Çaka) were very close to each other – differ only three years. Did they really differ three years or there was a mistake of recording the date. Three year difference is not a big difference in historical time. Therefore, there is a possibility that the two events were coeval and related to each other. In this relationship, the volcanic eruption stated as "guntur pawatugunung" has lead to the end of Majapahit as stated in the chronowords of "sirna ilang krtaning bhumi".

The significance of geological disaster in the decline of the Majapahit was proposed firstly by Sampurno in 1983 (Daldjoeni, 1992). Sampurno expected that volcanic eruptions from volcanic complex located close to the Majapahit : Anjasmoro, Welirang, and Arjuna – 25 kms to the southeast of the Majapahit area were responsible for the end of Majapahit as recorded in the

"guntur pawatugunung" chronicle (Figure 8). If these volcanoes erupted, the pyroclastic materials would flow along the Gembolo stream, into the streams of the Brantas River, flowing northwards and northwestwards. Pyroclastic massflow could also be generated from Gentong-Gowah-Gede at the volcanic slopes through Jurangcelot valleys entering the Jatirejo area and ended in the center of Majapahit Empire. The massflow could be initiated by a massive earthquake and a big flood. Sampurno in 1983 expected that the Majapahit could have its end suddenly facing this massive disaster.

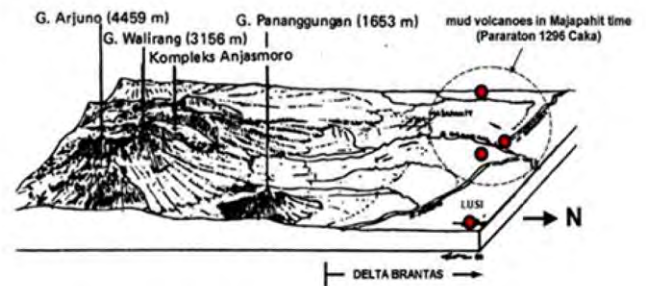


Figure 8. Block diagram of Delta Brantas, Lusi location, mud volcanoes of Majapahit time and magmatic volcanoes to the south of Delta Brantas (Arjuno, Welirang, Anjasmoro volcanoes). Some rivers have sources in the volcanoes and flowed to the area of Majapahit, eruption in the volcanoes could bring lahars or other volcanic materials into the Majapahit area. Map is modified after van Latwich (1936) in Daldjoeni (1992).

"Guntur Pawatugunung" could also be interpreted as mud volcano eruption instead of magmatic volcano eruption. Eruption of mud volcano can resemble eruption of magmatic volcano. The mud volcano eruption can cause a jet stream effect exploding massive blocks of rocks with thunder sound, bringing flammable gases which are burnt when they are exposed very rapidly into the air. In area where there are both mud volcano and magmatic volcano, like in East Java, the eruption of these two volcanoes can take place simultaneously and they are associated to each other. Helium gas will be erupted from mud volcano erupting close to the magmatic volcano.

Folklore of the Jenggala-Kediri Period "Timun Mas": Representing LUSI Events

Folklore called "Timun Mas" (literally means golden cucumber) developed in Jenggala and Kediri time does represent sequential events of mud volcano eruption like stages of occurrence of LUSI eruption. The folklore was possibly

composed by people of Jenggala to figure out the processes of mud volcano eruption in their period. Since Jenggala area was located at the elisional Kendeng Depression, it is possible that there were mud volcano eruptions during Jenggala time in 11th AD century. Folklore "Timun Mas" is a story containing natural (geological) process, this story tells the experiences of Jenggala People facing disaster.

The story has survived hundred of years told from older generations to younger generations to commemorate the significant event they underwent. Therefore, the folklore "Timun Mas" is something like a "dichtung und wahrheit" – a mixture between fiction and fact.



Figure 9. *Timun Mas, a folklore of East Java, showing Buto Ijo chases Timun Mas (Rahimsyah, 2010).*

The folklore tells about the poor widow named Mbok Sirni or Mbok Rondo, her daughter named "Timun Mas" (she originated from a golden cucumber –timun mas in local language), and the giant named Buto Ijo who wants to eat the daughter (Figure 9). Mbok Sirni lived alone after her husband died, but she wanted to have a child very much. One day she cried in the forest for her aloneness missing so much a child. Her cry was heard by a supernatural giant creature in the forest named "Buto Ijo" (means the green giant). Buto Ijo said to her that he can give her a child, but the child when she grows up should be given to him to eat. Mbok Sirni was confused with the giant's requirement but she eventually

agreed with that because she wants the child very much. Buto Ijo's requirement can be considered later, think Mbok Sirni. Buto Ijo gave her seeds of cucumber that should be planted. The child will come from cucumber, said Buto Ijo.

Mbok Sirni planted the seed and watered it regularly. The fresh cucumbers she sold in the market for her living. One day, she saw there was a cucumber growing so large and it was golden in color when the sun ray on it. Several weeks later, Mbok Sirni brought the cucumber to kitchen and cut it, she found the baby girl. Mbok Sirni named her "Timun Mas" (golden cucumber – from it came from).

Timun Mas grew up to become beautiful girl, Mbok Sirni loved her very much. Timun Mas was also a good daughter, she helped her mother in daily living.

One day when Timun Mas was 16 years old, the ground was shaken like earthquake happens, Buto Ijo appeared in front of Mbok Sirni's house. He asked for Timun Mas to eat as Mbok Sirni promised him teens of years ago. Mbok Sirni told the giant that the child is still too small to eat and requested two years more for the child to grow up so that it will be more satisfied for the giant to eat. Buto Ijo agreed Mbok Sirni's request and he went to the forest.

Two years later he will come again to eat Timun Mas. Since then, Mbok Sirni was sad thinking the fate of her daughter. She prayed every day and night to have a way to free Timun Mas. One night she heard a Voice ordered her to visit an old hermit living in a hill far from her village. The day after she went there as following the direction from the Voice. After several days of walking and she was so tired, she met the place where the hermit lived. She met him and told the story. The hermit listened to Mbok Sirni's story and gave her four things to free her daughter from the giant: seeds of cucumber, needles, salt, and terasi (a local condiment made from pounded and fermented shrimp or small fish). These things should be used one by one in order from seeds of cucumber to terasi when Buto Ijo wants to catch Timun Mas. Mbok Sirni returned happily to her village and tell Timun Mas what to do.

One day ground was shaken again like earthquake and Buto Ijo appeared again to ask for Timun Mas to be eaten. Mbok Sirni commanded Timun Mas to run away immediately and bringing four things from the hermit. Buto Ijo was angry to the widow and saw Timun Mas ran away from her house. Buto Ijo immediately chased her. The earth

shook again like a strong earthquake happened when Buto Ijo chased Timun Mas.

As Timun ran, Timun Mas remembered her mother's command, she threw away the seeds of cucumber that suddenly became the field of cucumbers. Buto Ijo stop for a while because he was thirsty and hungry, he ate up all cucumbers voraciously.

Having his stomach full, Buto Ijo chased again Timun Mas. Timun Mas threw needles. Needles immediately became the bamboo forest. Buto Ijo was painful chasing Timun Mas because the bamboos stabbed his body but due to his superpower, he was able to overcome the bamboo forest and chased Timun Mas again. Timun Mas was so tired but she should keep running away.

She threw salt into the giant when he was very close to catch her. The salt suddenly became the body of salted water like a sea lake (Figure 10). Buto Ijo was surprised by this attack and he sank into the sea, but again he survived and ready to chase Timun Mas.

At the end, Timun Mas threw terasi into the sea. A hard explosion was heard when terasi fell into the sea and hot boiling muddy sea water suddenly appeared to change the sea. This sank again Buto Ijo. Buto Ijo fought himself to make him free from the hot muddy water, but he was so tired and the mud was so dense and hot to fight, Buto Ijo asked for help to Timun Mas and promised not to eat her, but the giant could not survive and met his death in the hot boiling muddy sea water (Figure 10).



Figure 10. *Timun Mas folklore (Ashari, 1999).*

That is how Timun Mas folklore ends happily.

Considering this folklore, it contains factors which are very similar to the orders of LUSI (Lumpur Sidoarjo) mud volcano eruption when it happened: there was an earthquake, there was lake of salted water like sea, there was an explosion, and there was an eruption of hot muddy water.

Based on the historical analysis, the folklore has its origin from the 11th AD century in the Jenggala time in present Sidoarjo area. From our previous discussion, we know that the Jenggala's center positioned in the same area where LUSI is erupting today (Figure 11).



Figure 11. *Mud volcano eruption of Lusi today (source: BPLS).*

Accordingly, the content of the folklore Timun Mas has a possibility to be composed by people of Jenggala to illustrate the disaster of mud volcano eruption that they witnessed at that time. In Indonesia, folklore is commonly composed to illustrate significant natural process taking place in former times when people did not understand what actually happened, and a folklore is selected as a media to inform and record the event of disaster to remember from generation to generation (Dananjaya, 1984).

Geology of Jenggala and Majapahit Areas: Elisional Kendeng Depression

As we discussed previously, Jenggala and Majapahit areas were positioned at the eastern part of the Kendeng Depression covered by sediments of the Brantas Delta (Figures 1 to 3).

The Brantas Delta has been mobile and compressed. Underlying the Brantas Delta, there are seven anticlinal belts trending west-east formed in the Plio-Pleistocene (Figure 6). The deformation on anticlines is still taking place in Quaternary time and several of the deformations took place in historical Kahuripan, Jenggala, and Majapahit periods as recorded in historical chronicles to divert the flow of the Brantas River (Nash, 1931; Daldjoeni, 1992).

Duyfjes (1938) who mapped quadrangle of map sheet-116 (Sidoarjo) investigated the deformation activities of this area in detail (scale 1: 100,000).

The anticlines that he mapped has presented in Figures 2 and 6.

The Kendeng Zone is one of the youngest tectonic features in the eastern Java area. It was formed virtually at the early to late Pliocene (Lunt et al., 1996). It was part of a continuously subsiding basin from Miocene to the end of the middle Pleistocene. Late Miocene and older sediments in the Kendeng Zone are typically thick, interbedded mudstones and volcanoclastic sands. The marls and limestones of the Lower and Upper Kalibeng Formation were deposited in almost entirely marine environment during the Pliocene.

During the early Pleistocene, marine blue clays of Pucangan were deposited in the east where finally volcanic deposits prograded (Duyfjes, 1938). The gravity data of the Kendeng Zone shows strongly negative anomalies indicating considerable depth to the basement in the Kendeng Zone. The Kendeng Zone is the deepest part of the Java's depression from Bogor-North Serayu-Kendeng-the Madura Strait (Figure 2).

The Kendeng Zone is strongly folded and sometimes heavily faulted in the western part. Structuring is very recent and is probably still active. Fold axes in this area are oriented in E-W direction; an indicator that the adjacent and parallel volcanic chain is, at least in part, is responsible for compression. In the east, south of Surabaya where numerous mud volcanoes occur, the folds are nearly lost under recent alluvium and even Pleistocene rarely crops out (Figure 6).

The Kendeng Depression/Zone is the best elisional basin in Indonesia therefore, numerous mud diapirs and mud volcanoes occur here. Young tectonic feature, subsided basin, compressed, very thick young sediments deposited rapidly in relatively short period, and thermally significant due to nearby volcanic arc make the Kendeng Depression to be elisional. High sedimentation rate initiated during Upper Miocene – Early Pliocene time causing deposition of a very thick highly overpressured sedimentary succession. Clayey and silty sediments interbedded with sand beds contain great amount of fluids. The presences of overpressured sediments, less dense plastic shale succession underlying denser beds and saturated with the fluids, and high tectonic activity favors the mud diapirs and mud volcanoes development in the region. Presently erupting-LUSI mud volcano provides good opportunity to know the origin of mud volcanoes in the Kendeng Depression. All other active, dormant, and extinct

mud volcanoes in the Kendeng Depression have their origins with the elisional system of the Kendeng Zone, including expected mud volcanoes of Jenggala and Majapahit periods. The main Kendeng Depression has existed since 5 Ma; it has been compressed since then. It can be expected that mud volcanoes in the Kendeng Depression were triggered by tectonics and seismicity like most mud volcanoes in the world originated. Further discussion of this is provided by Satyana and Asnidar (2008, 2019).

Conclusions

The Brantas Delta and its underlying Kendeng Depression, where Jenggala and Majapahit Empires existed from 11th to 16th AD Century, show an elisional system causing the occurrences of mud diapirs and mud volcanoes. LUSI mud volcano, which has been erupting since May 2006 is a present evidence showing the effectiveness of the elisional system in the Brantas Delta-Kendeng Zone. There are numerous mud volcanoes in this area. The paper argues that eruptions of mud volcanoes also took place in the Jenggala-Majapahit period and they affected the decline of these two empires. The constraints for this consideration are based on historical chronicles which recorded natural disasters, local folklore, geologic analysis of the Jenggala-Majapahit area, and field analogue to LUSI mud volcano.

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