A link between Lusi and the volcanic complex?

.....Insights from gas geochemistry

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Triggering hypotheses

Based on drilling data interpretation: two conflicting hypotheses

a) Man-made

b) Not man made

Based on field observations and experimental data:

a)Evidence of earthquake-fault reactivation connection

Natural trigger option: what is the role of the volcanic arc in all this?

The bigger picture: regional observations

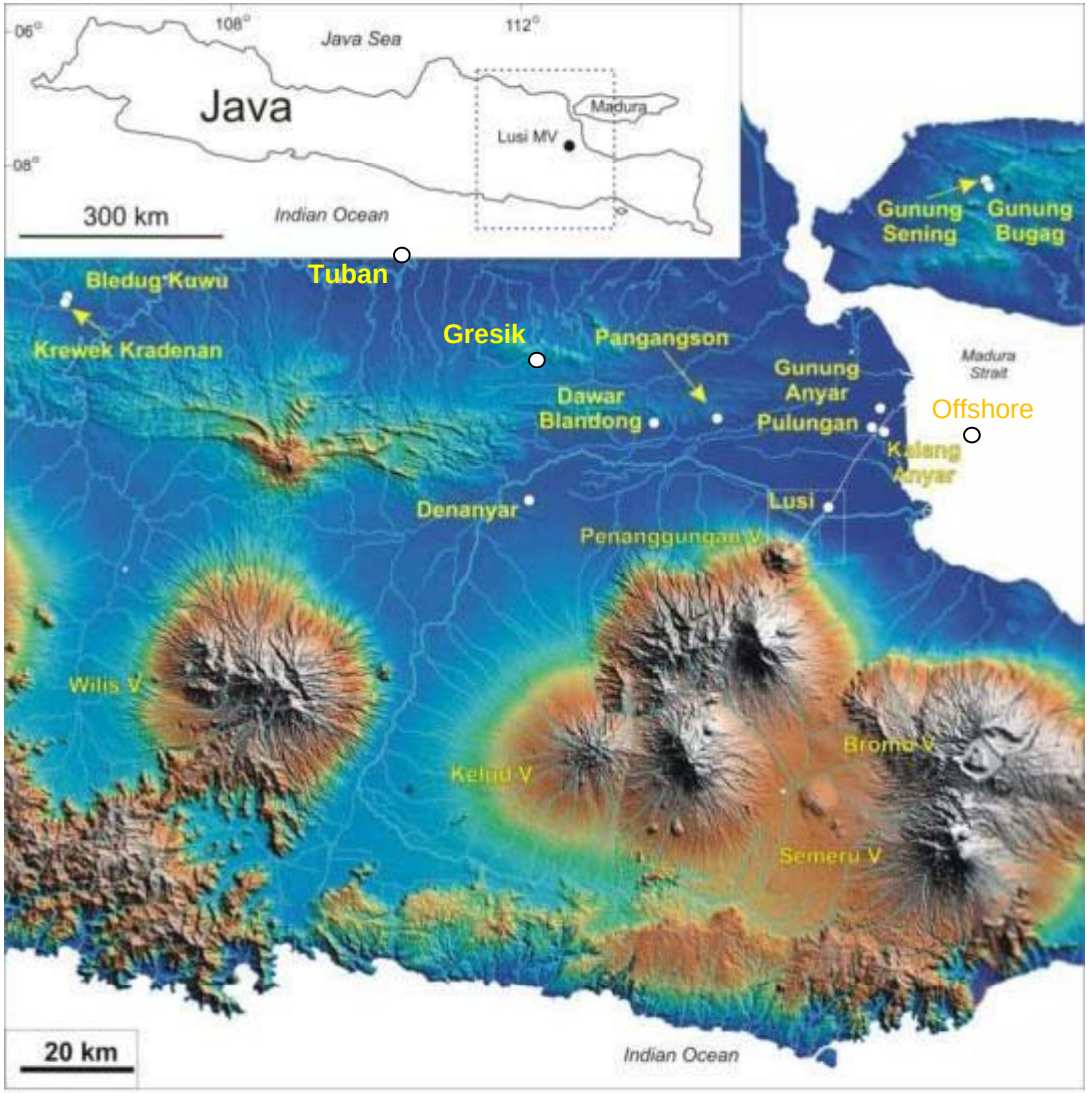
Field observations and key findings in eastern Java:

a) Numerous mud volcanoes and seeps → Lusi not the only mud eruption site

b) Lusi is aligned along a major fault zone → External trigger plausible

c) Proximity to the volcanic arc → Influence of deep volcanic system?

Key findings: mud volcanism is common



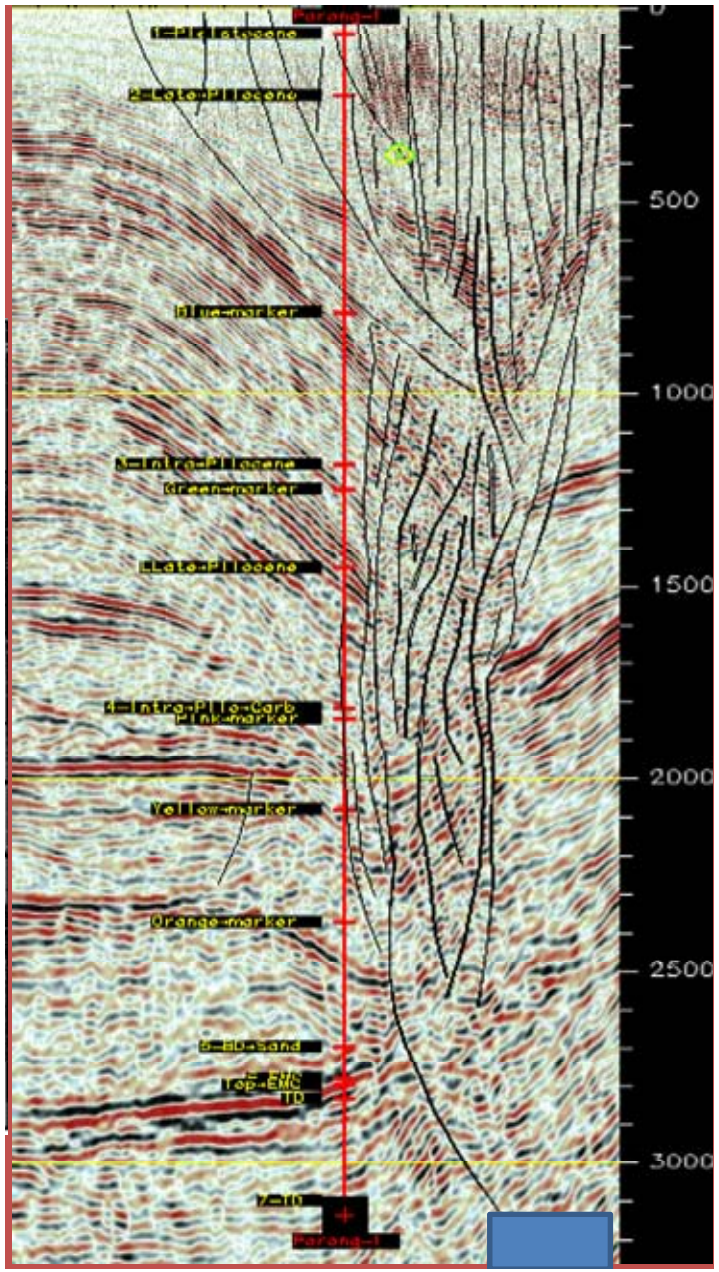
Mud volcanism is a very common phenomenon in Indonesia

The geological setting of Java: text book example for mud volcano formation

Has there ever been a Lusi in the past? Likely, based on geological and historical data

Mazzini *et al.* 2009

Key findings: mud volcanism (?) in the past

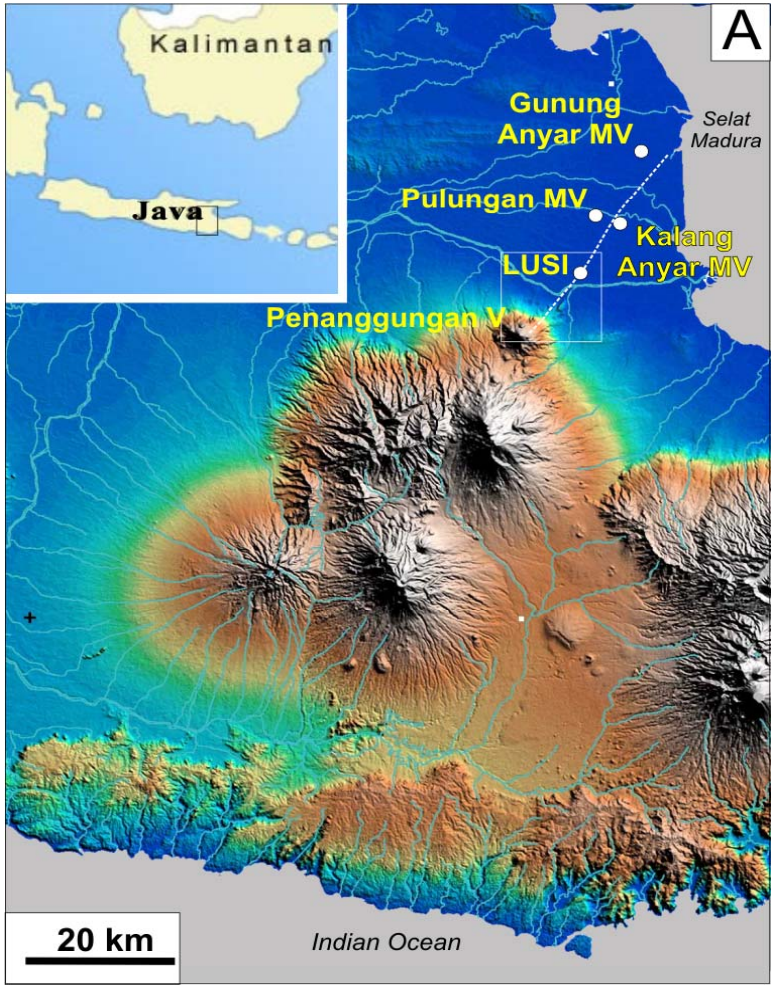


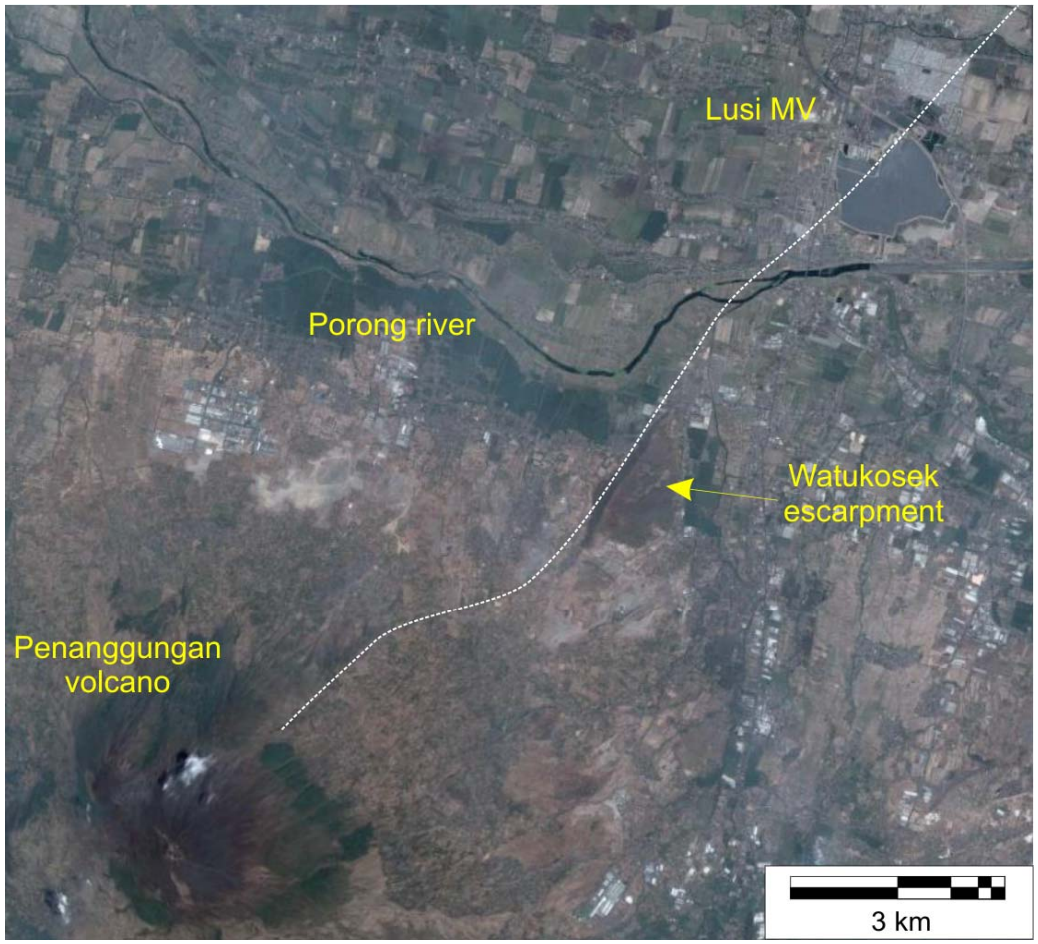
Porong structure located few kilomets NE of Lusi

- **Collapse structure**
- **Presence of an ancient piercement structure**
- **Related to mud volcanism (?)**

Istadi *et al.* 2009

Key findings: Lusi along the Watukosek Fault system



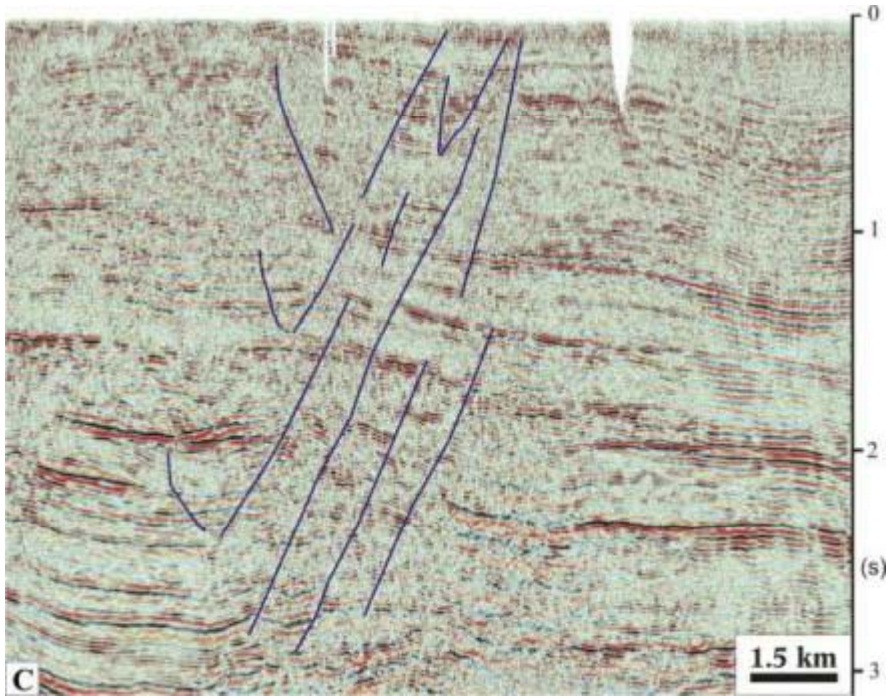


Watukosek fault hosts other mud volcanoes on NE Java

Geological features clearly indicate the presence of the fault (dashed line)

Mazzini *et al.* 2009

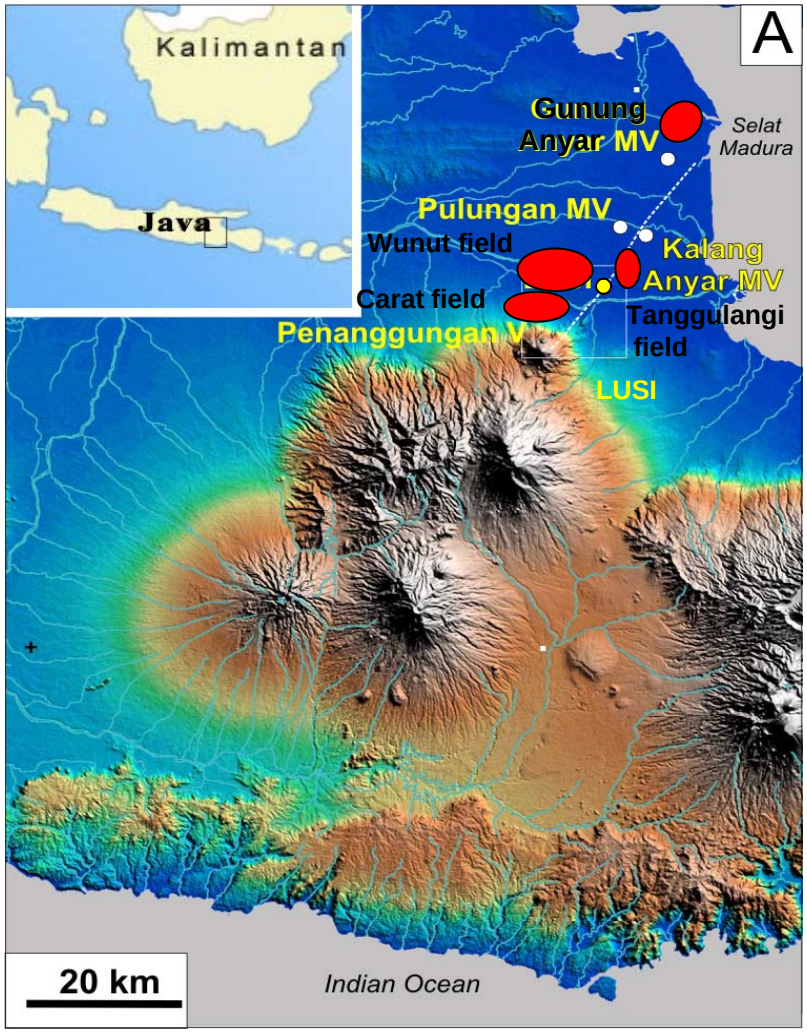
Key findings: Watukosek Fault at depth



Seismic profiles collected during 1980's sistematically show the presence of a fulted zone both on the SW and NE of Lusi site

Mazzini *et al.* 2009

Pressure loss at various wells in May 2006

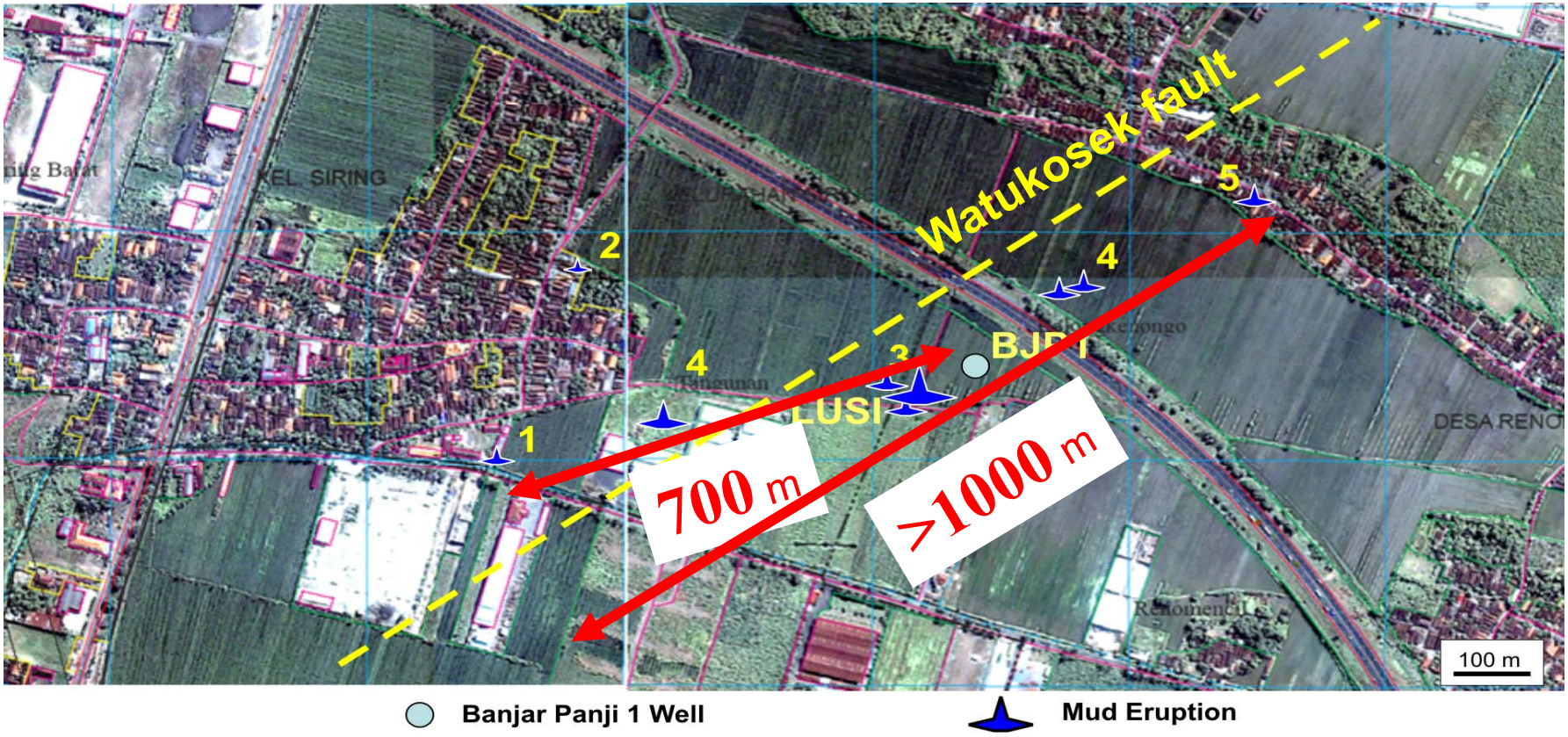


Interestingly Wunut, Carat, Tanggulangin gas and oil fields and the water wells close to Gunung Anyar report sudden pressure loss after the 27-05-2006 earthquake.

→ Fluids flushed away from aquifer

Mazzini *et al.* 2009, MPG

Key findings: May 2006: several mud and gas eruptions suddenly appeared



- **First eruption 700 m from drilling site**
- **Sequence of eruptions oriented along a > 1000 m SW-NE trend**

Mazzini *et al.* 2007

Key findings: aligned eruption sites

Eruptions follow the Watukosek fault direction

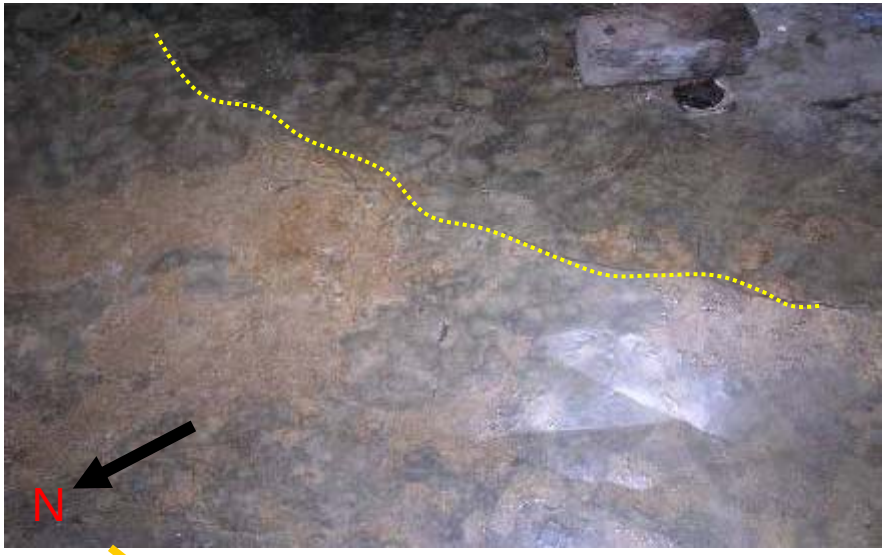
(numbers refer to previous image, listed in chronological sequence)

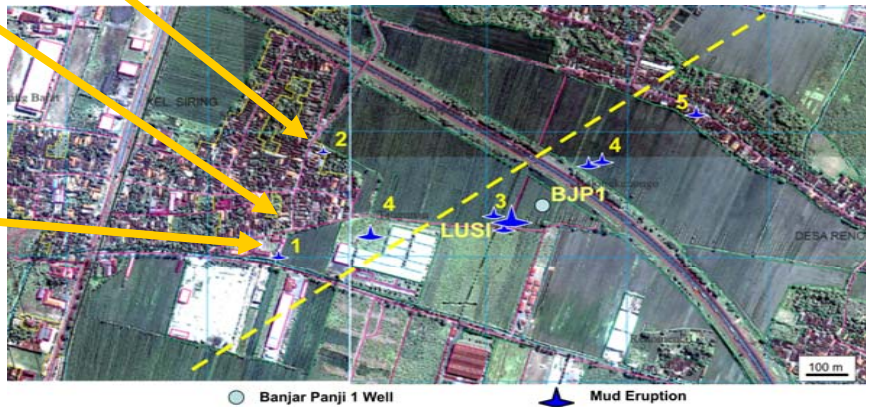
Mazzini *et al.* 2007, EPSL

Key findings: LUSI prograding cracks after EQ

Fractures follow the Watukosek fault direction

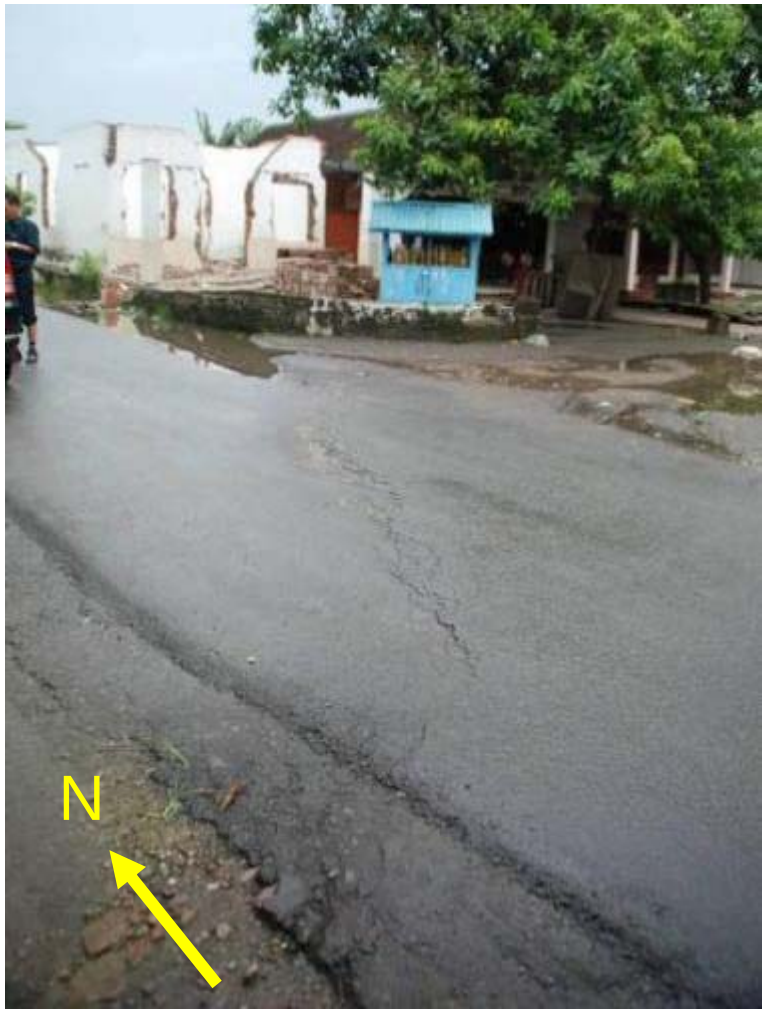
Key findings: LUSI prograding cracks after EQ





Prograding cracks observed through the village after EQ. **follow the Watukosek fault direction**

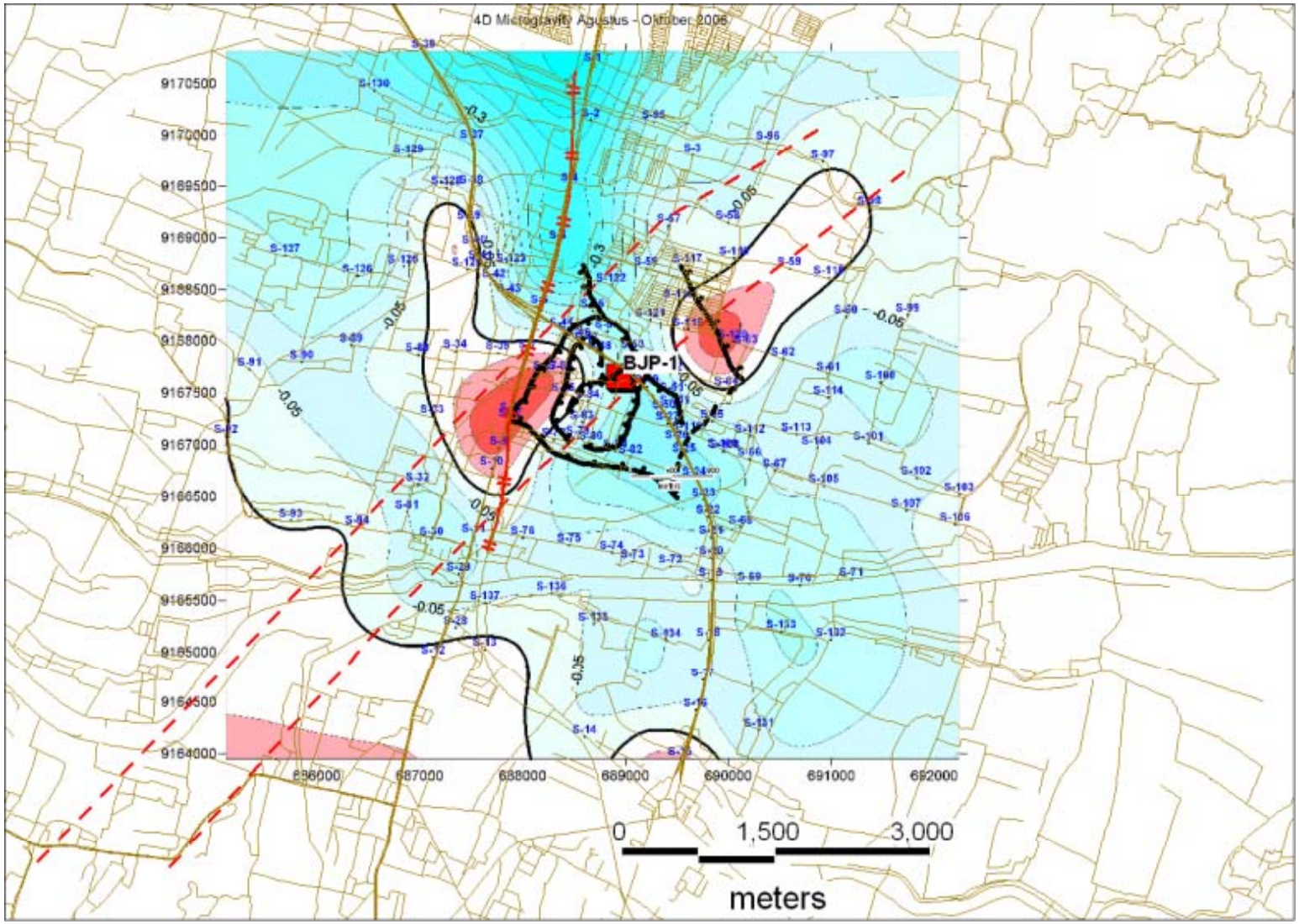
Key findings: faulting north of LUSI



Faulting follows the Watukosek fault direction

Mazzini *et al.* 2009

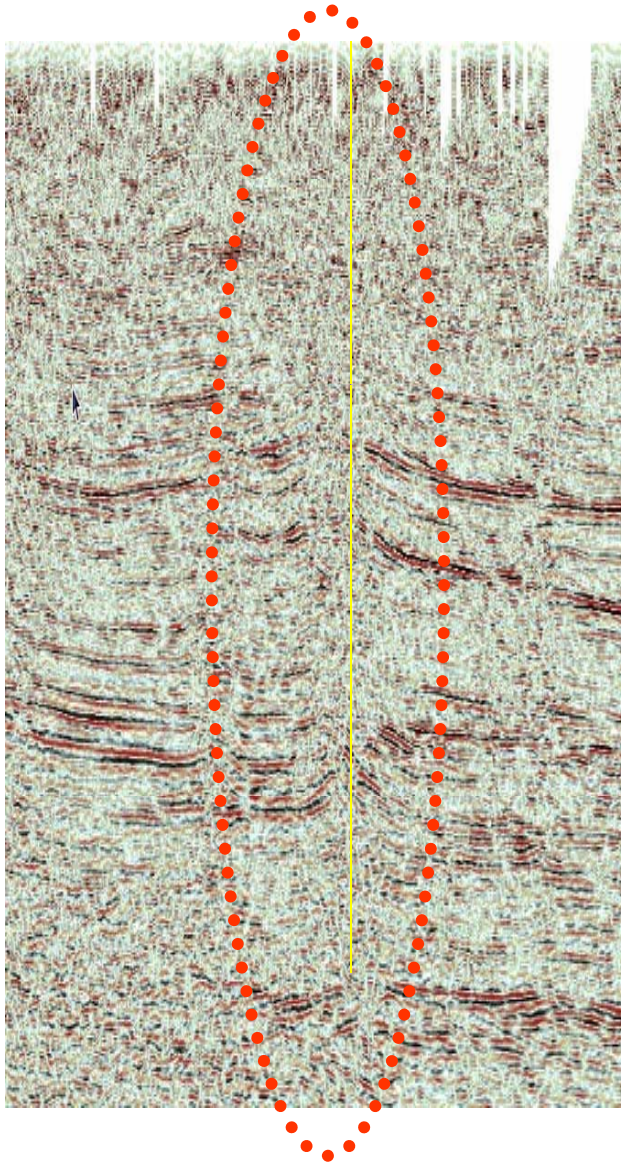
Key findings: Collapse/new seeps follow fault trend



Subsidence monitoring October_august 2006

Istadi *et al.* 2009

Key findings: seismics show pre-existing piercement



Seismic profiles from 1980's show presence of growing piercement structure at Lusi site.

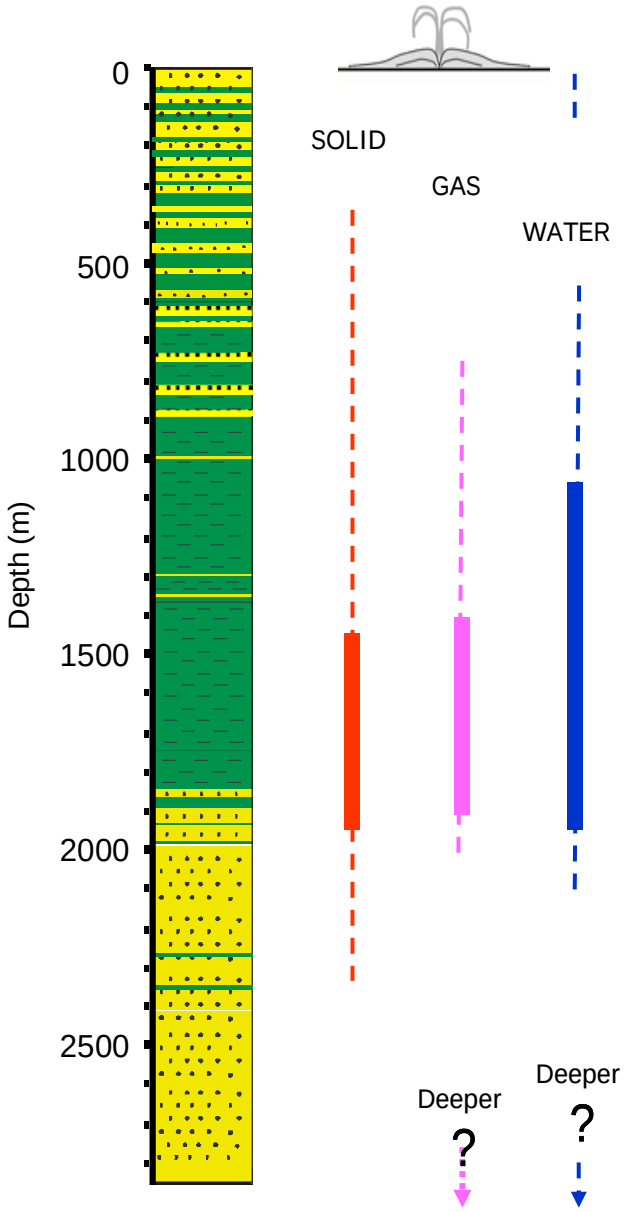
Typical of gelogical features that will manifest to the surface

→Lusi would have erupted sooner or later

Mazzini *et al.* 2007

Key findings: Origin of erupted solid/fluids

(based on observations made in 2006)



Keypoints

- The LUSI system formed in a geological setting prone to mud volcanism
- Main gas CO_2+CH_4+acqueous vapour
- Illitization throughout clayey unit

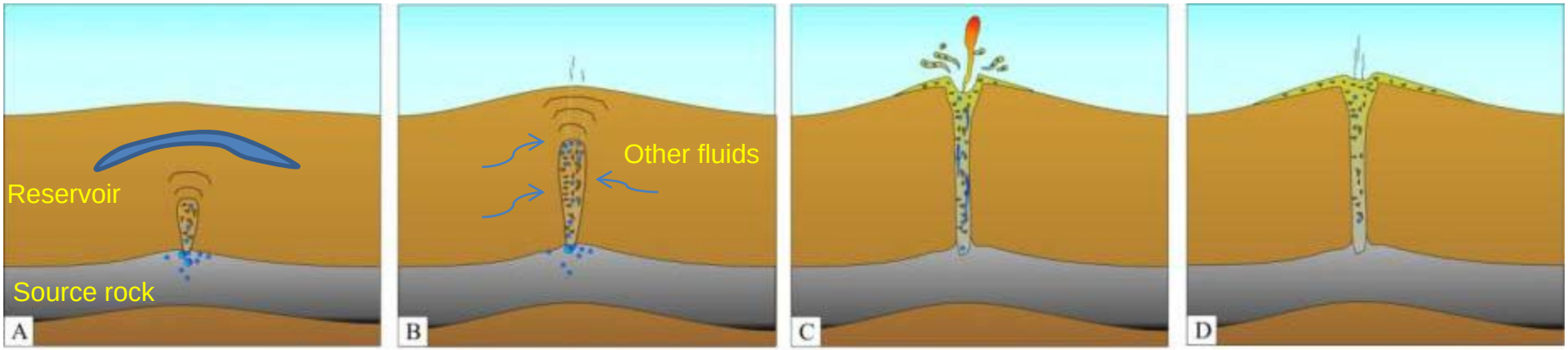
- Main source for water-gas-mud 1100-1850 m
  Large amount of water available
- Possible deeper source of water/gas NOT obvious from sample analyses.

Mazzini *et al.* 2007

What is Lusi?

MUD VOLCANISM

"Geological phenomena made manifest through the sudden eruption or quiescent extrusion of sediment, rock, and fluids from deeper strata of an hydrocarbon bearing basin"



Fluid overpressure in impermeable sediments, diapiric structure formation and brecciation during diapiric growth

Overpressured diapir reaches critical depth. Overburden cannot contain gas saturated diapir

Blast of gas. The sudden pressure release allows large amount of fluidized and gas saturated sediments to reach the surface

Fluid-rich mud eruption following to initial blast. Slow seepage continues even during dormant period releasing remaining fluids

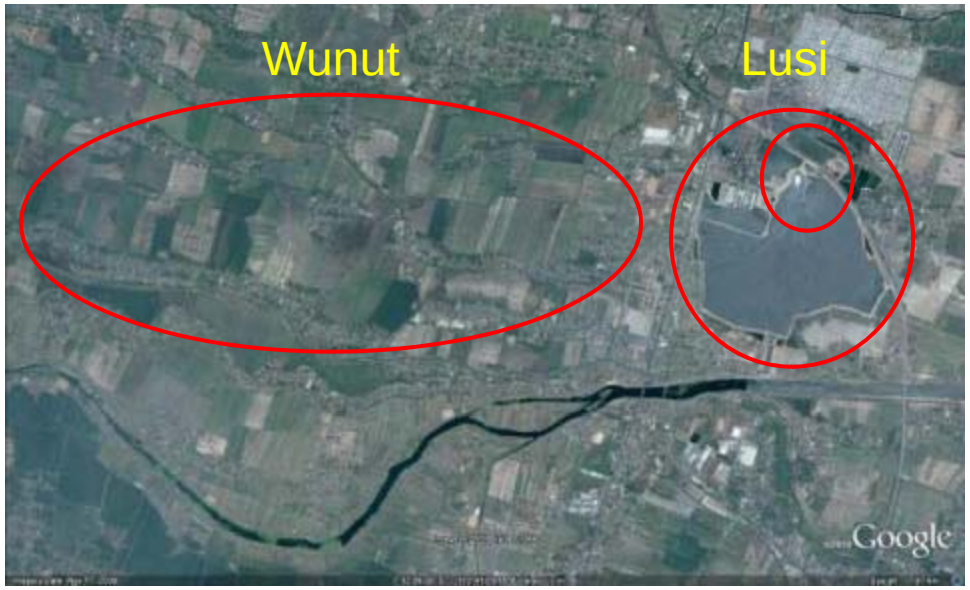
Mazzini *et al.* 2009

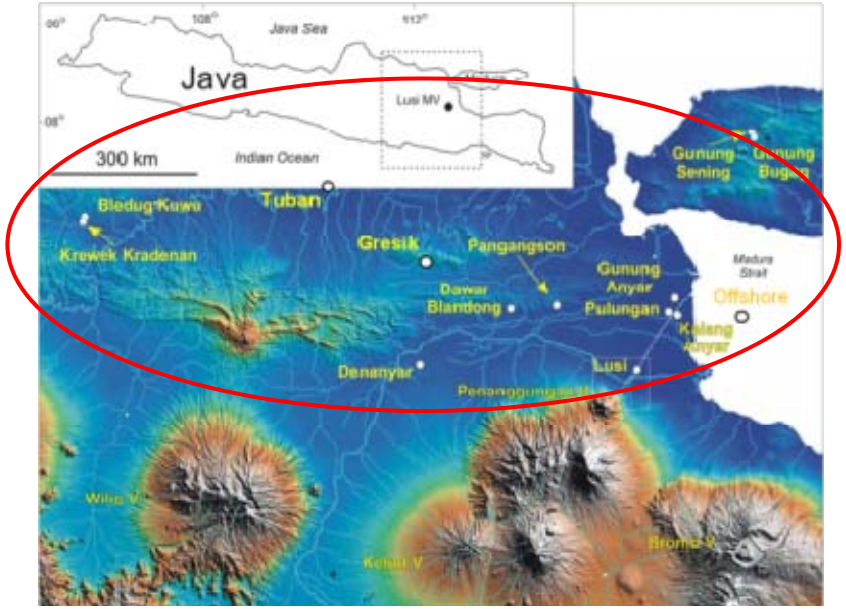
Is Lusi really a mud volcano?

- **TYPICAL FOR MUD VOLCANO**
- **Setting**
- **Morphology**
- **Presence of mud breccia**
- **Water from illitization of clay minerals**

- **ATYPICAL FOR MUD VOLCANO**
- **High geothermal gradient (shallow geochemical reactions)**
- **Longlasting eruption**
- **Pulsating behavious (geyser-like?)**
- **CO_2-dominated gas**

Sampling 2006-2010 (34 samples)





Group 1: **HOT** fluids from main crater (CO_2-dominated)

Group 2: **COLD** fluids from satellite seeps (CH_4 - dominated)

Similar isot. comp

Group 3: fluids from Wunut gas field

Group 4: Fluids from MVs in east Java

Methane zonation diagrams

Diagrams indicate that

- **Lusi 2006: the early sampling made in 2006 shows contributions of microbial CH_4 component (Kaliberh Fm. + alluvial)**
- **Lusi after 2006: thermogenic signature**
- **Wunut: thermogenic signature (although very shallow)**
- **Other MVs in east Java: mixed gas**

Hydrocarbons maturity plots

- **Maturity plots indicate a deep origin of Lusi gas.**
- **Lusi plumbing system is much deeper than previously expected**
- **Lusi gas was generated at high temperatures**
- **Wunut gas is more fractionated compared to Lusi**

CO_2 and helium origin

- **CO_2 gas isotopic composition indicates that high temperature reactions generated the erupted gas**

- **Helium isotopic values and CO_2/CH_4 also indicate high equilibrium temperatures as well as presence of mantle origin fluids**

- **Hot fluids are involved in the ongoing geochemical reactions**

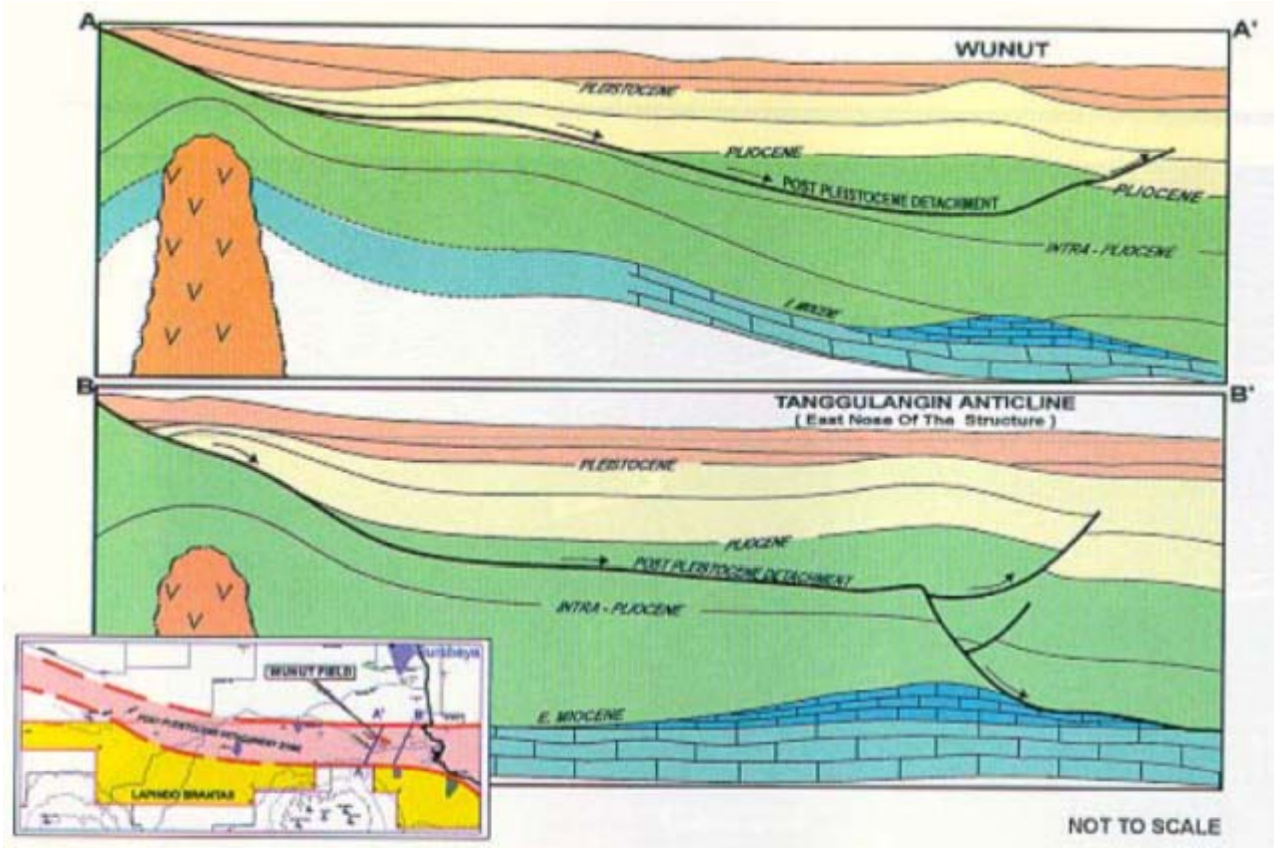
A new scenario for the lusi eruption

An intrusion and/or hot fluids form the neighbouring Arjuno-Welirang volcanic complex explains the observations indicating that it is responsible for:

- **High geothermal gradient**
- **Significant CO_2 production**
- **High temperature generation of CO_2 and CH_4**
- **Presence of mantle gas**

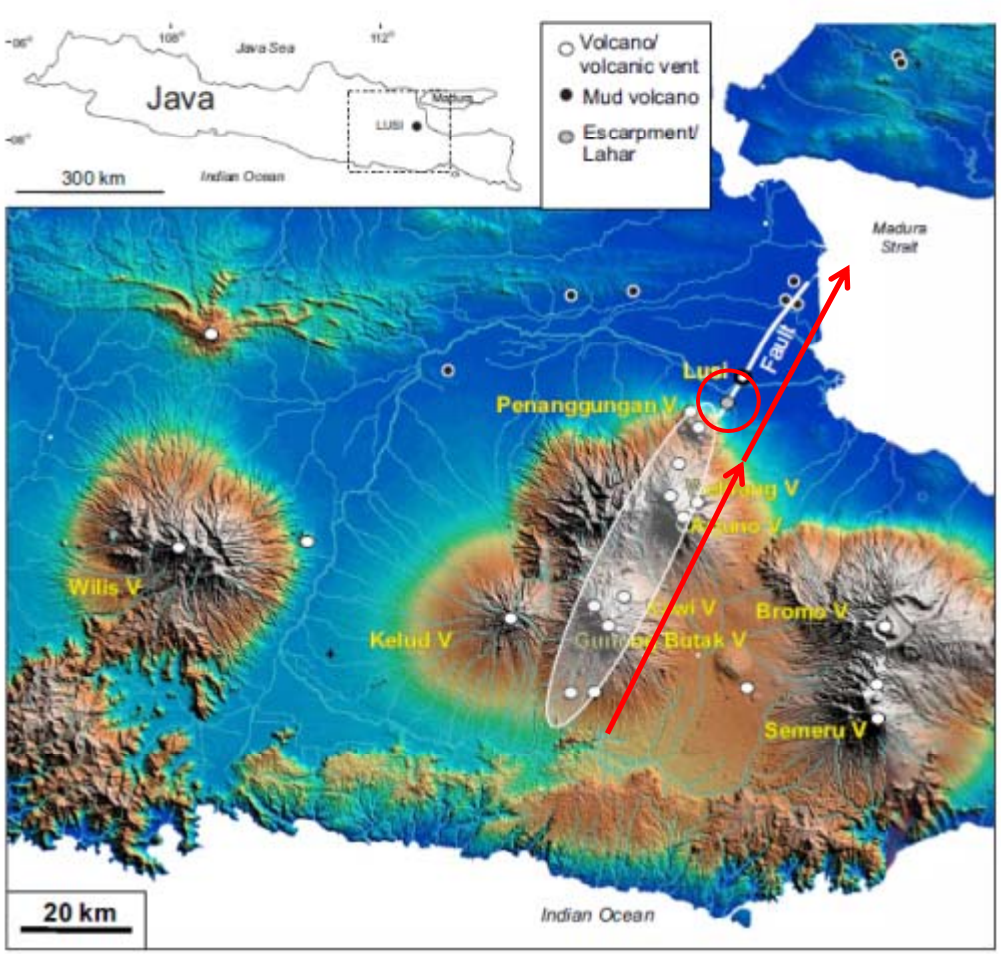
The intrusion scenario

Possible intrusion from the neighbouring volcanic complex already suggested in 1999



Kusumastuti *et al. 1999*

The Arjuno-Welirang volcanic complex



- Growth of the **complex** evolving **towards the NE**

- **Watukosek** fault system follows the same **NE direction** hosting other mud volcanoes

- Evidence of **hot fluids interaction** along the escarpment

Seismicity?

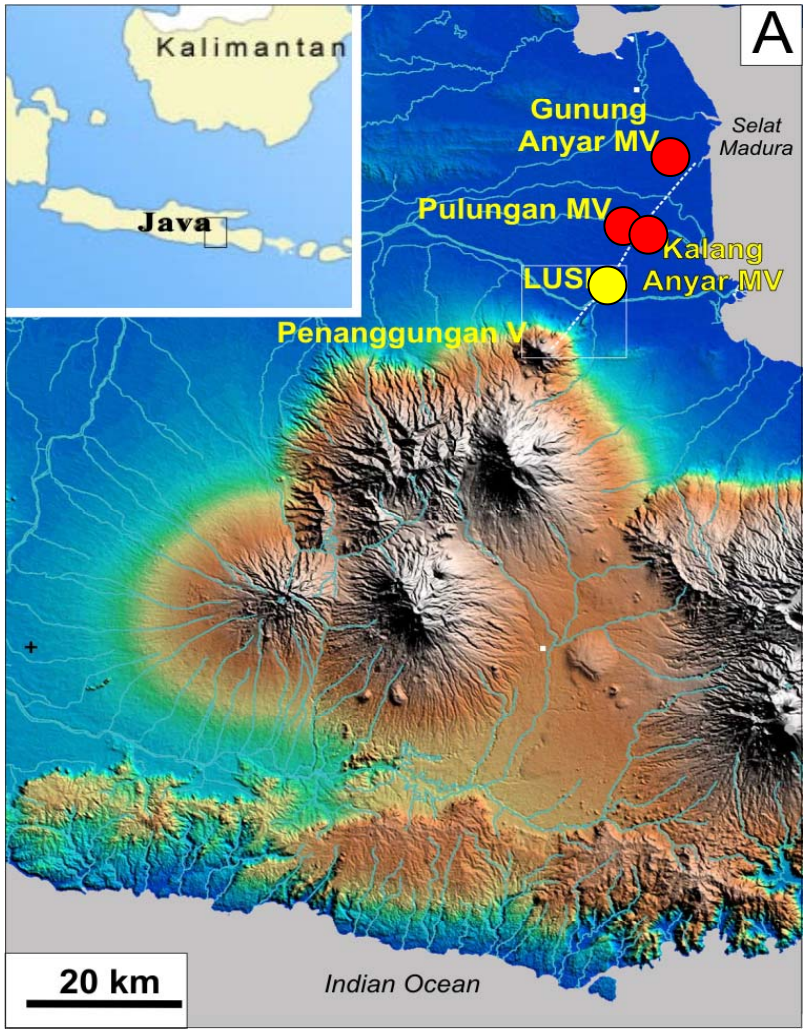
Is the frequent seismicity affecting the system:

Lusi

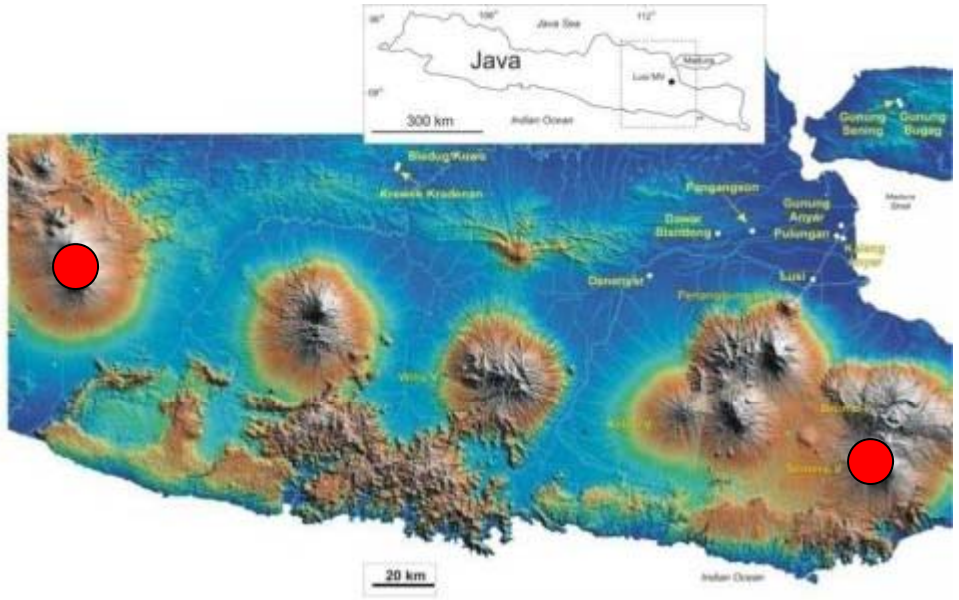
Fault

Volcanic system?

Increased activity of other mud volcanoes along fault after May 2006 earthquake

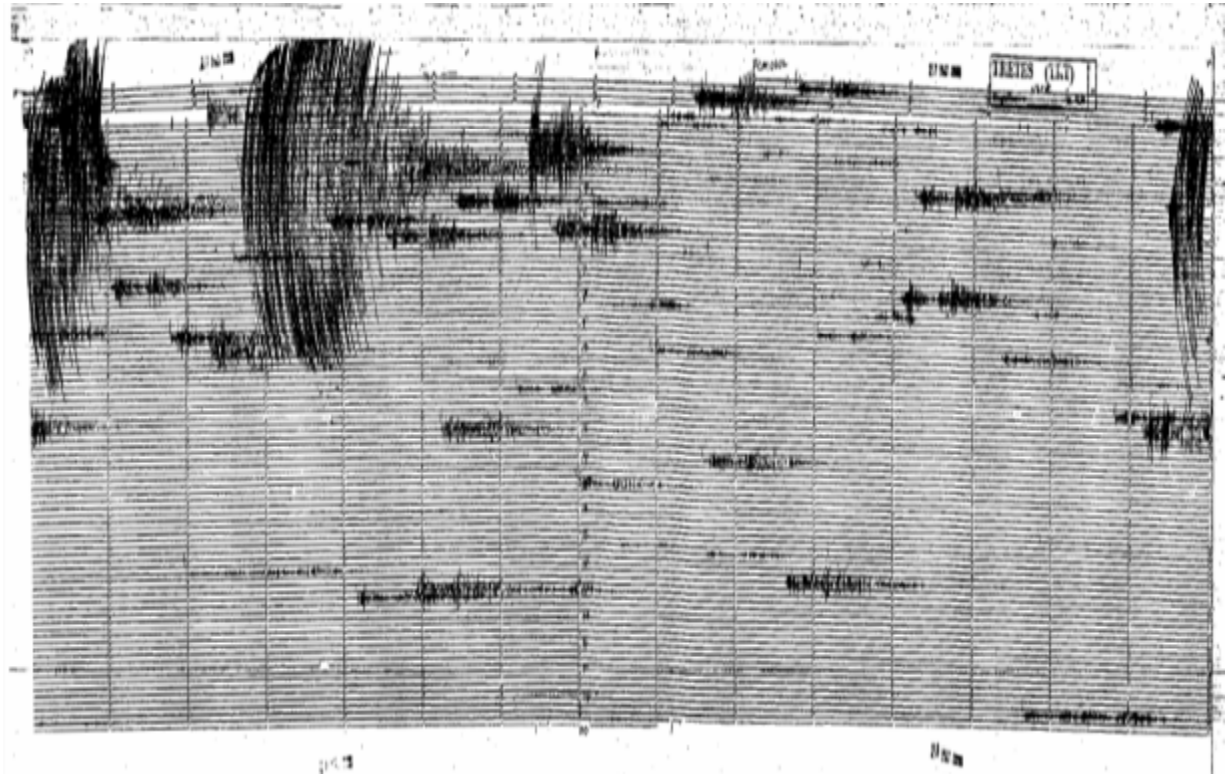


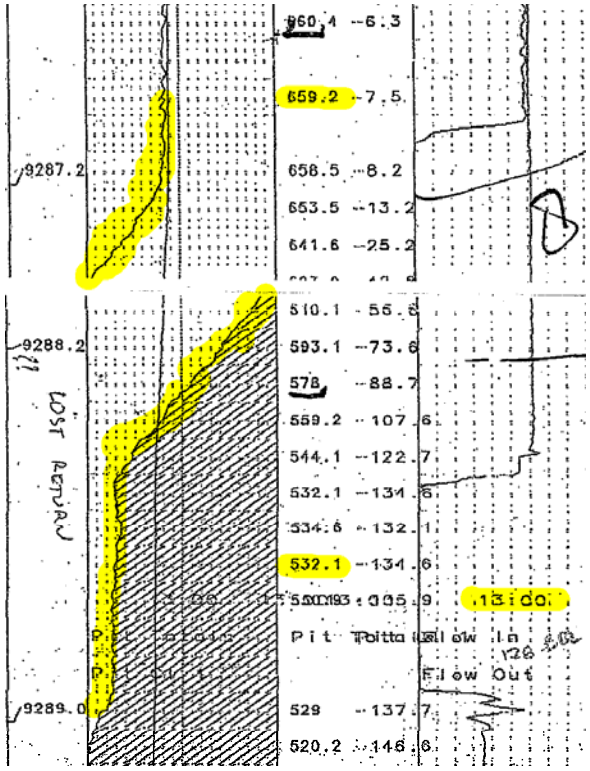
Coincidentially other mud volcanoes along Watukosek fault were more active after earthquake when activity started around Lusi.



Semeru + Merapi stronger activity after earth quake

Earthquake and loss of circulation at drilling site





Coincidently partial loss of circulation after the earthquake and total loss of circulation following the two after shocks

Sawolo *et al.* 2009

Lusi response after earthquakes

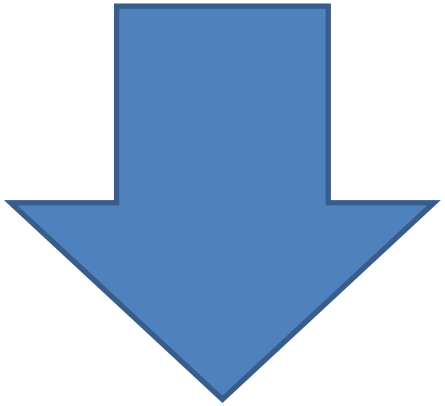
- **Since 2006, in numerous instances Lusi appeared to respond to seismic activity (see Mazzini *et al.* 2007, 2009)**

- **Recent seismic activity (i.e. 2011) also revealed prompt response of Lusi behaviour**

Mazzini *et al.* 2009, MPG

Predictions about Lusi longevity

- **Combined effect of:**
  - **Seismicity**
  - **Alterations of magmatic chamber**
  - **Reactivation of Watukosek fault**



  - **Effect on rheology of sediments and critical overpressure**

Summary

Lusi is part of a larger sediment-hosted hydrothermal system connected to the Arjuno-Welirang volcanic complex

A deeper sited magmatic intrusion or migration of hot fluids explains the geochemical signature observed

Lusi cannot be a representative example of a mud volcano


terima kasih

References

- Istadi, B.P., Pramono, G.H., Sumintadireja, P. and Alam, S., 2009. Modeling study of growth and potential geohazard for LUSI mud volcano: East Java, Indonesia. Marine and Petroleum Geology, 26(9): 1724-1739.
- Mazzini, A., 2009. Mud volcanism: Processes and implications. Marine and Petroleum Geology, 26(9): 1677-1680.
- Mazzini, A., Nermoen, A., Krotkiewski, M., Podladchikov, Y., Planke, S. and Svensen, H., 2009. Strike-slip faulting as a trigger mechanism for overpressure release through piercement structures. Implications for the Lusi mud volcano, Indonesia. Marine and Petroleum Geology, 26(9): 1751-1765.
- Mazzini, A., Svensen, H., Akhmanov, G.G., Aloisi, G., Planke, S., Malthe-Sorenssen, A. and Istadi, B., 2007. Triggering and dynamic evolution of the LUSI mud volcano, Indonesia. Earth and Planetary Science Letters, 261(3-4): 375-388.