
THE UNIVERSITY OF ADELAIDE
AUSTRALIA
The Science Behind The East Java Mud Flow ('Lusi')
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Trees ~ 10 m high
Photo courtesy Bakrie Media Centre


The Sidoarjo Mud Flow, East Java– One Year On
• BACKGROUND
• MUD VOLCANOES
• ERUPTION TRIGGERS
• LUSI – FUTURE SCENARIOS
Photo: M. Tingay May 2007

Birth of Lusi – Mud Eruption 29th May 2006

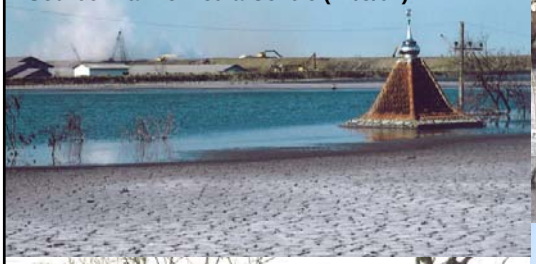
Lusi: 2nd August 2006

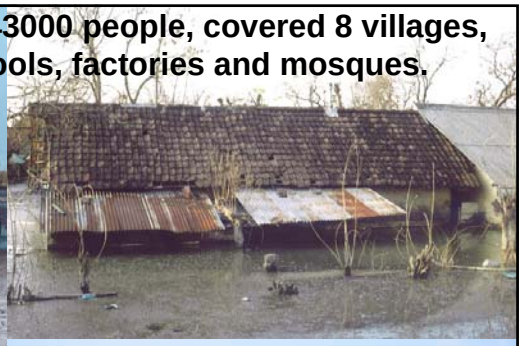
Flow rates started at ~5000 m^3/day and have reached ~150000 m^3/day, averaging at ~100000 m^3/day. Locals report that some homes were completely inundated in <15 minutes.

Photos courtesy of Bakrie Media Centre

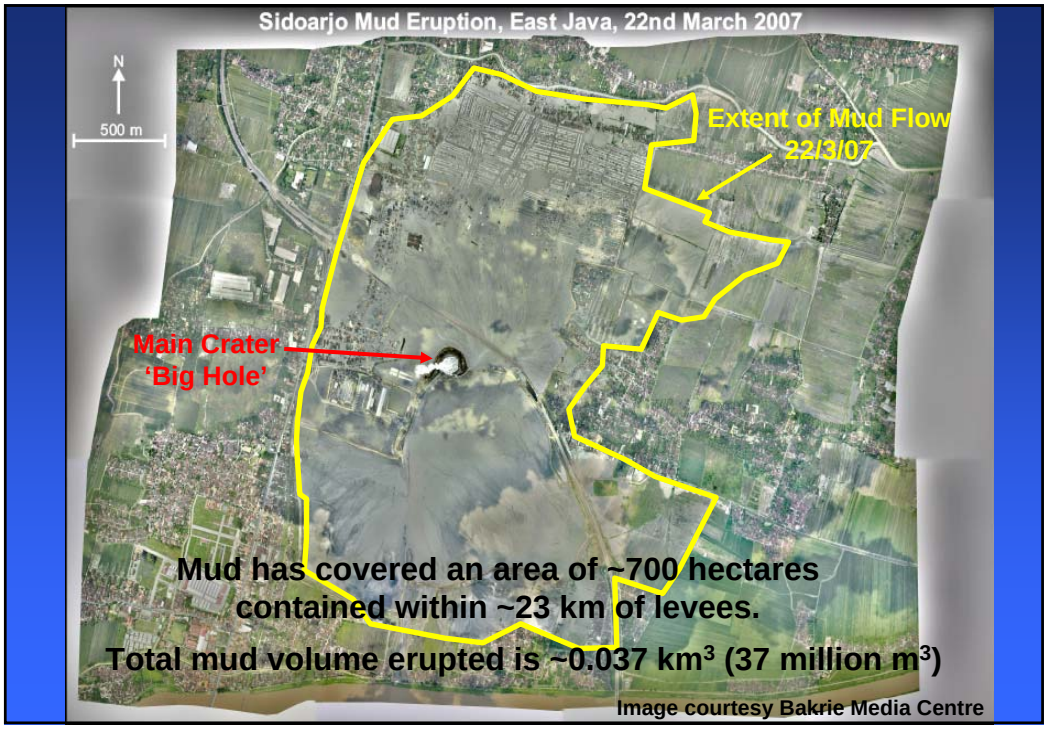
Mud flow has displaced 27000-43000 people, covered 8 villages, >4000 homes and ~100 schools, factories and mosques.

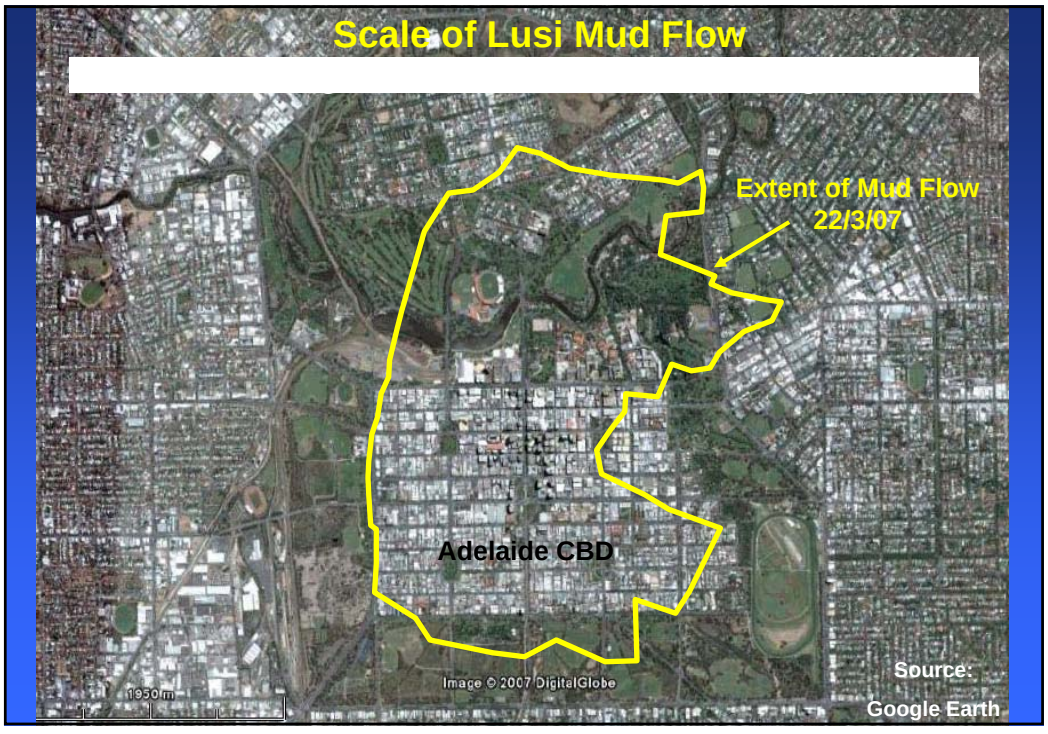
Source: Bakrie Media Centre (24/5/07)





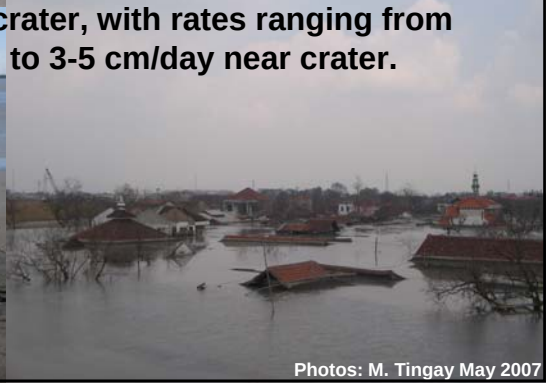
Photos: M. Tingay May 2007


Sidoarjo Mud Eruption, East Java, 22nd March 2007
N
500 m
Extent of Mud Flow
22/3/07
Main Crater
'Big Hole'
Mud has covered an area of ~700 hectares
contained within ~23 km of levees.
Total mud volume erupted is ~0.037 km3 (37 million m3)
Image courtesy Bakrie Media Centre


Scale of Lusi Mud Flow
Extent of Mud Flow
22/3/07
Adelaide CBD
1950 m
Image © 2007 DigitalGlobe
Source:
Google Earth

Mud Eruption has caused extensive subsidence in the 2km around the crater (~1000 hectares), threatening >100000 homes.

Subsidence is ~17m near crater, with rates ranging from 2-3 cm/month at edges to 3-5 cm/day near crater.



Photos: M. Tingay May 2007

The Sidoarjo Mud Flow, East Java– One Year On

- BACKGROUND
- **MUD VOLCANOES**
- ERUPTION TRIGGERS
- LUSI – FUTURE SCENARIOS

Photo: M. Tingay May 2007

Mud Volcano Basics

Mud volcanoes are where subsurface mud is extruded at the surface.

Mud volcanoes can be lakes/pools ('salses') or cones ('gryphons') and can be small features (cm's) or up to 250 m high and several km's wide.


Gryphon, Gobustan


Gryphon, Dashgil


Salse, Dashgil


Kotrdag – 200m high

All examples from Azerbaijan. Photos M. Tingay 2006 and 2007

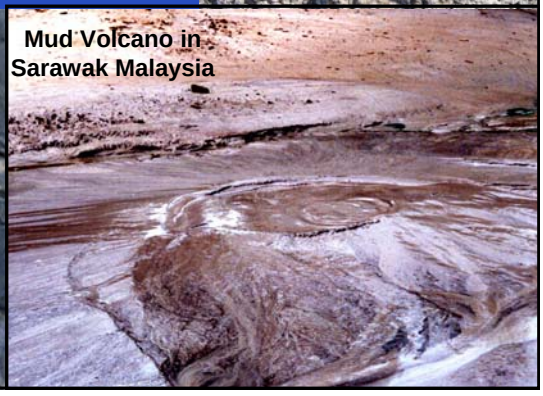
Mud Volcano Basics

Often associated with hydrocarbons.

Mostly 'cold' and caused purely by depositional conditions, but can also be linked to magmatic volcanism (e.g. New Zealand).


Oily mud volcano in Azerbaijan
Photo M. Tingay 2006


Cold mud in Azerbaijan, Photo M. Tingay 2005


Mud Volcano in Sarawak Malaysia

Worldwide Occurrence of Mud Volcanoes

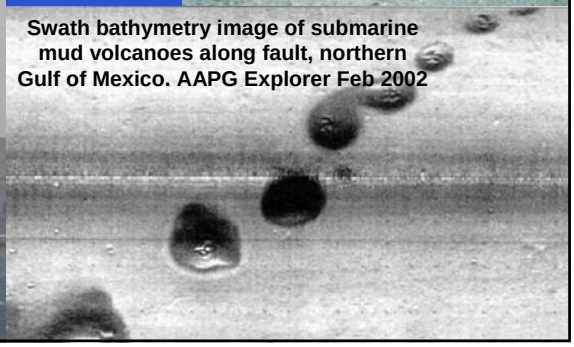
Predominately submarine, but also occur in many onshore areas (e.g. Azerbaijan, Iran, Trinidad).

Mud volcanoes are common in rapidly deposited basins (especially Tertiary deltas) and sedimentary basins in tectonically active regions.

Eruption rates typically small (1's-100's m^3/day), but can erupt violently for short periods (in the order of 10^5-10^6 m^3/day).

Mud Volcano, Wyoming
Photo S.R. Brantley, USGS

October 2001 major eruption of Lokbatan, Azerbaijan (Aliyev et al. 2002)



Swath bathymetry image of submarine mud volcanoes along fault, northern Gulf of Mexico. AAPG Explorer Feb 2002

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What Triggered the Lusi Eruption?

Although details on mechanics vary slightly, the theories on what triggered the mud eruption can be separated into two distinct and competing groups:

1. Eruption is the natural birth of a mud volcano that was triggered by 27th May 2006 Yogyakarta earthquake.

2. Mud eruption triggered by internal blowout in Banjar Panji-1 well, which inflated shallow reservoirs, subsequently fracturing them to extrude mud at the surface.

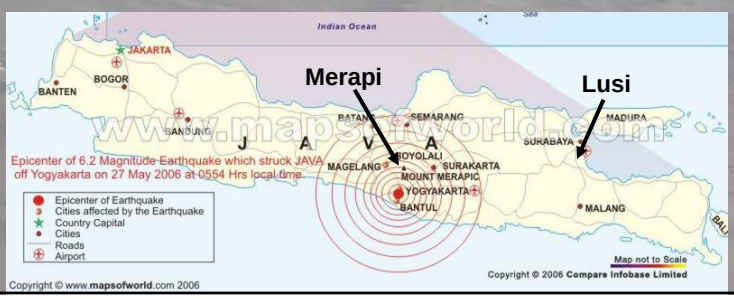
Earthquake Trigger For Lusi?

Yogyakarta in Java (280km from Lusi) was shook by a Magnitude 6.2-6.4 earthquake two days prior to the eruption (~2.0 magnitude at Lusi).

Earthquake occurred at 5.40am local time on the 27th of May 2006 and killed an estimated 6000 people.

Theory suggests that quake caused faults/fractures to open and become permeable between 800-3000 m depth, enabling overpressured fluids to entrain mud and escape to surface.

Note: The Yogyakarta quake is believed to have triggered a 2-3 fold increase in eruption rates in the Merapi Volcano (50km from quake) 3-12 days after quake (Harris & Ripepe, 2007).



Evidence for Earthquake Eruption Trigger

A natural mud volcano (Gunung Anyar) is located only about 30 km from Lusi.

There is evidence of faulting following the eruption, suggesting fault triggered eruption (OR eruption triggered faulting!).

Some scientists suggest that vast fluid flow rates (150000 cubic metres per day) are not possible through a 12.25" borehole.

There are examples of more proximal and higher magnitude earthquakes causing mud volcano eruptions offshore of Iran in 1945 (Makran earthquake) and March 1999 (Malan Island formation; Kopf, 2002).

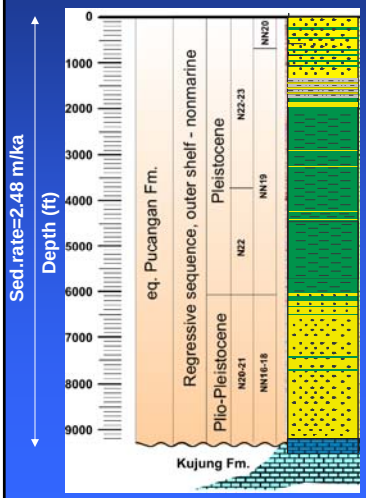
Shallow gas storage reservoirs in Japan have been breached due to earthquakes, resulting in fluid eruptions (Kumai & Yamamoto, 2007).

Original proflie and location of Gunung Anyar (now eroded)

Photos: Bakrie Media Centre

Drilling-Induced Trigger for Lusi?

Banjar Panji-1 well (operated by Lapindo (50%), with non-operating partners Medco (32%) and Santos (18%)) spudded on 9th March, targeting gas in the Oligo-Miocene Kujung Fm carbonates.



700-1940 ft: littoral to inner shelf Pleistocene alternated sand-clay

1940-5500 ft: inner to outer shelf Pleistocene clayey unit

5500-9297 ft: Pleistocence turbidite systems (volcaniclastic sand and clay)

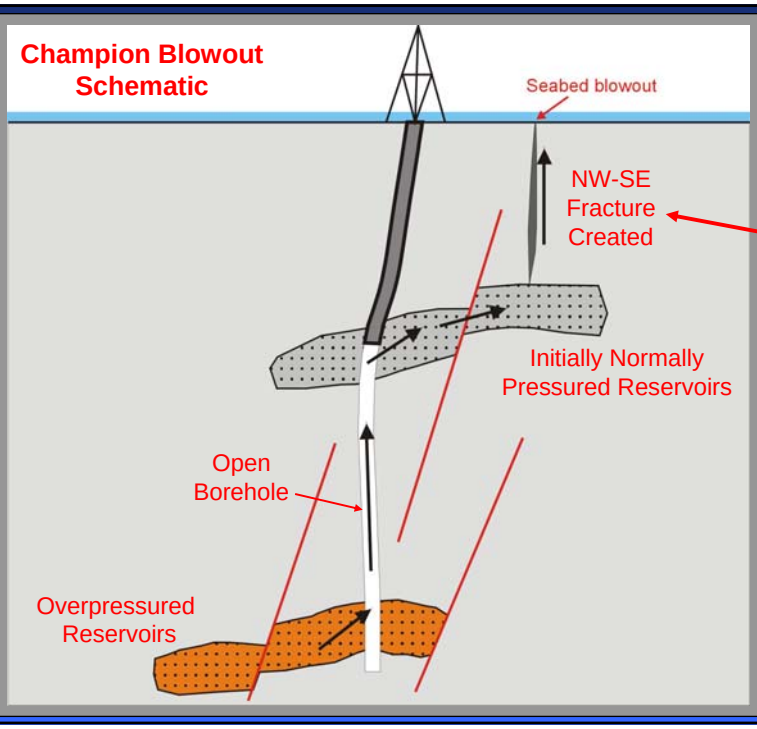
Early Miocene reefal and open marine carbonate facies (Kujung Formation)

Drilling-induced trigger theory claims that mud eruption results from a surface rupture following an **'internal blowout'.**

Image from: Mazzini et al. (2007)

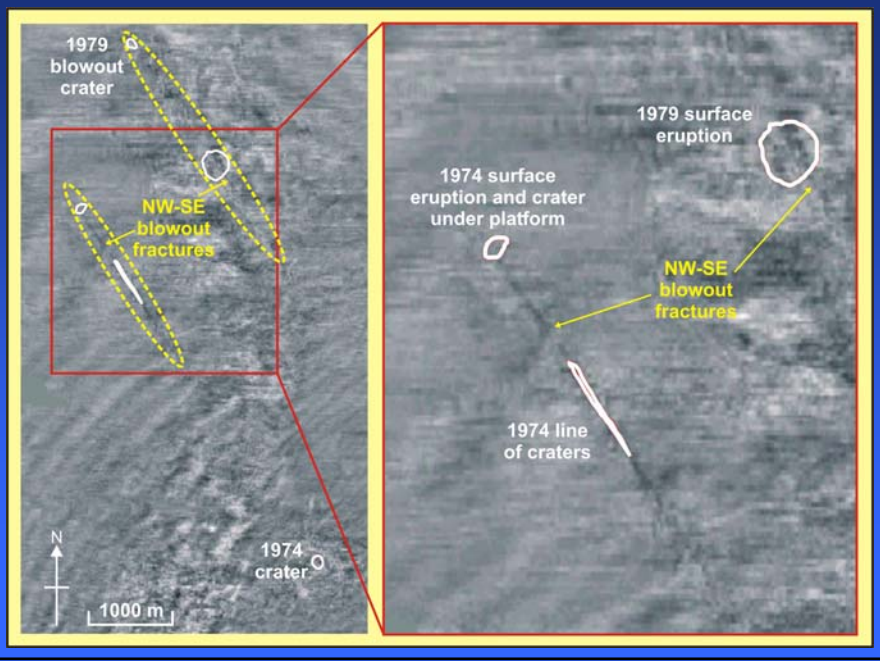
1979 Champion Field Blowout, Offshore Brunei

Internal blowout lasted for over 20 years. Kept under control by series of over 20 relief and monitoring wells producing between 1000-8000 m^3 per day.



Onshore shale dyke as fracture analogue

Shallow seismic time slice over blowouts in the Champion Field



Platform A Blowout, January 1969 off Santa Barbara California

Well drilled in contravention of federal laws with no surface casing and only 238 feet of conductor casing. Well blew out at rig when pumps stopped for logging.

Workers eventually managed to control well site blowout after 12 days, but soon after oil and gas started erupting several hundred feet from the platform.

Subsequent studies revealed five fractures in the sea floor due fracturing following the internal blowout.

Estimated that ~100000 barrels of oil spilled by eruption, which lasted 100 days.

Oil and gas erupting into ocean near Platform A

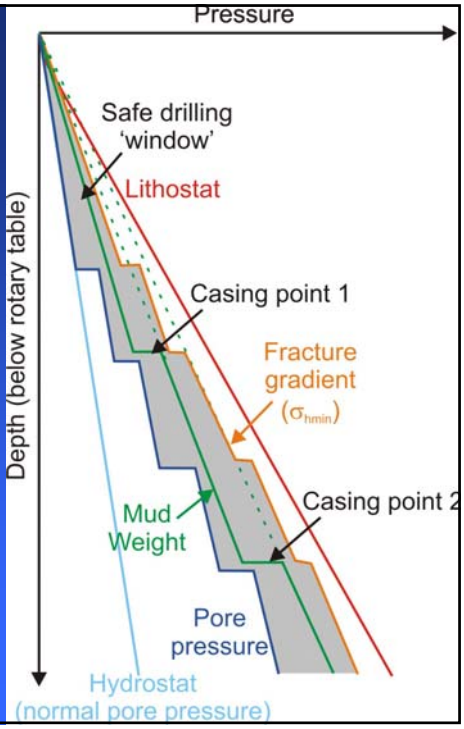
Source: County of Santa Barbara, Energy Division

Why Is It Important to Set Casing?

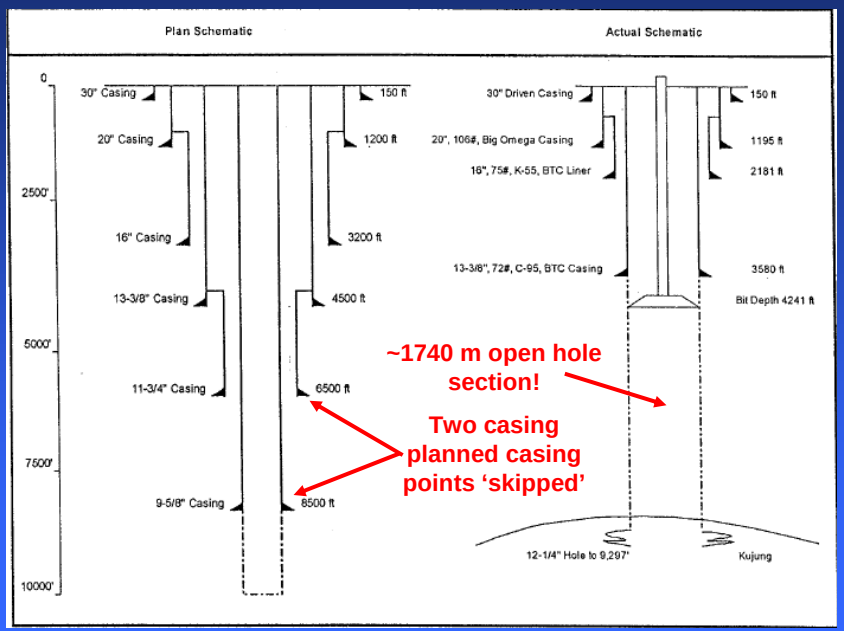
Mud weight must always be maintained between pore pressure (to avoid kicks/blowout) and fracture pressure (to avoid losses and fracturing) – known as the 'safe drilling window'.

Casing is set to strengthen upper section of hole and allow higher mud weight to be run, thus maintaining a safe drilling window.

Major internal blowouts typically occur when drilling window 'closes' – where fracturing of the well near casing shoe makes it impossible to maintain a bottom hole mud pressure greater than the pore pressure.



Planned versus Actual Casing Design in Banjar Panji-1



From Sutriono (2007)

Events during Drilling of Banjar Panji-1

- Drilling began on 9th March 2006.
- 13 3/8" casing set at 1091 m on 30th April (280m shallower than planned). Planned casing points at 1980m and 2590m were 'skipped'.
- Complete loss of circulation occurred ~7 hours after earthquake (~12.30pm) on the 29th May while drilling at ~2830m. LCM run to try to control losses, attempt made to POOH and cement.
- Losses reports are variable. Some reports state some partial losses 10 minutes after quake, one report claims loss of circulation occurred 6 hours before quake!
- Whilst pulling out, well kicked at 8am on the 28th May when bit at ~1290 m. String and bit was later cut and dropped (snubbing and fishing attempt suggested that bit still lodged at this depth).
- Kick possibly due losses lowering bottom hole mud weight or due to pressure surges or 'sucking' out formation fluids. Lusi began ~21 hours later.
- Lapindo claim that kick was killed within 4 hours and that they were able to circulate and test borehole for fractures in the hours after Lusi erupted (test type unknown and there are conflicting reports about whether the kick was killed).

Sources: Bakrie Media Centre; Davies et al., 2007; Mazzini et al., 2007; Santos Incident Briefing 8/12/2006

Internal Blowout in BP-1?

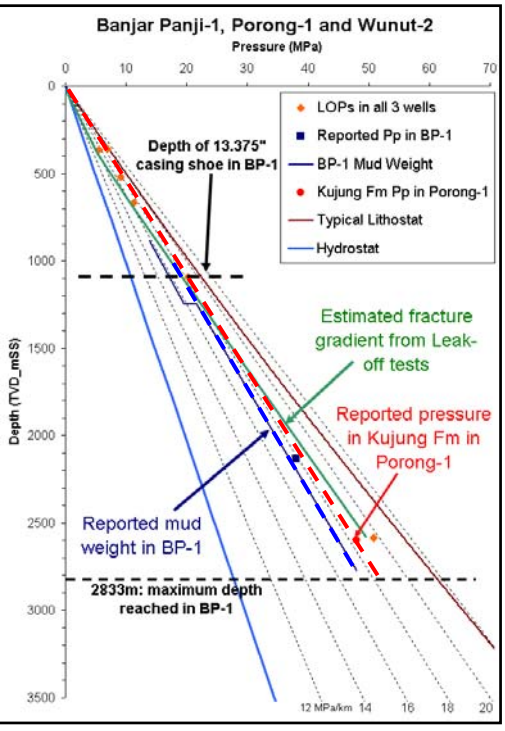
Published static mud weights are below fracture pressure (Sutriono, 2007), and so losses should not occur, but safe drilling window is very narrow.

However, pore pressures greater than these mud weights are reported in BP-1 and extremely high pressures are reported in the Kujung Carbonates in Porong-1 (Davies et al., 2007).

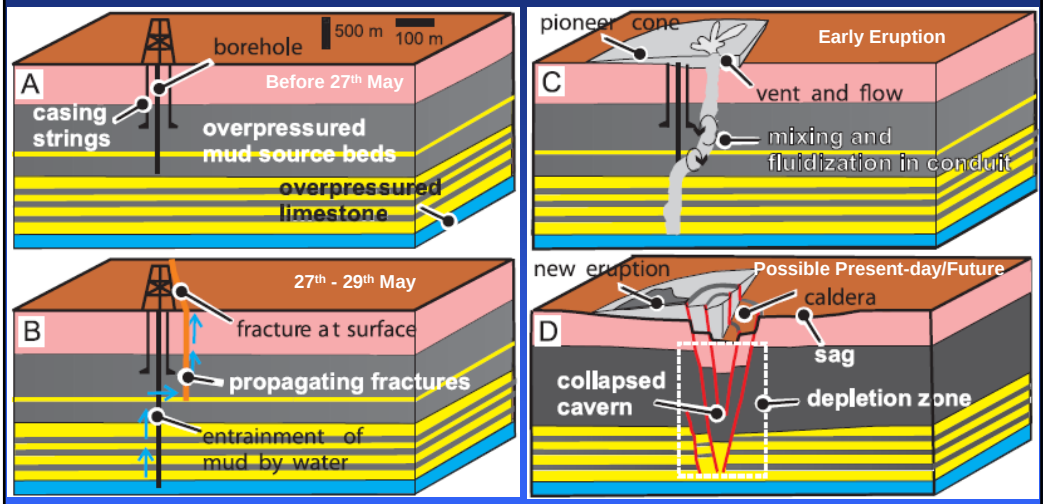
Unofficial comments indicate that mud weights were raised shortly before losses commenced.

Increase in mud weight by <1 MPa/km would cause severe losses (and circulating density not taken into account), and subsequent kick.

However, inconsistencies in drilling conditions and tests need to be addressed.



Schematic Model for Drilling-Induced Triggering of Lusi



From Davies et al., 2007 (based upon Champion blowouts in Brunei).

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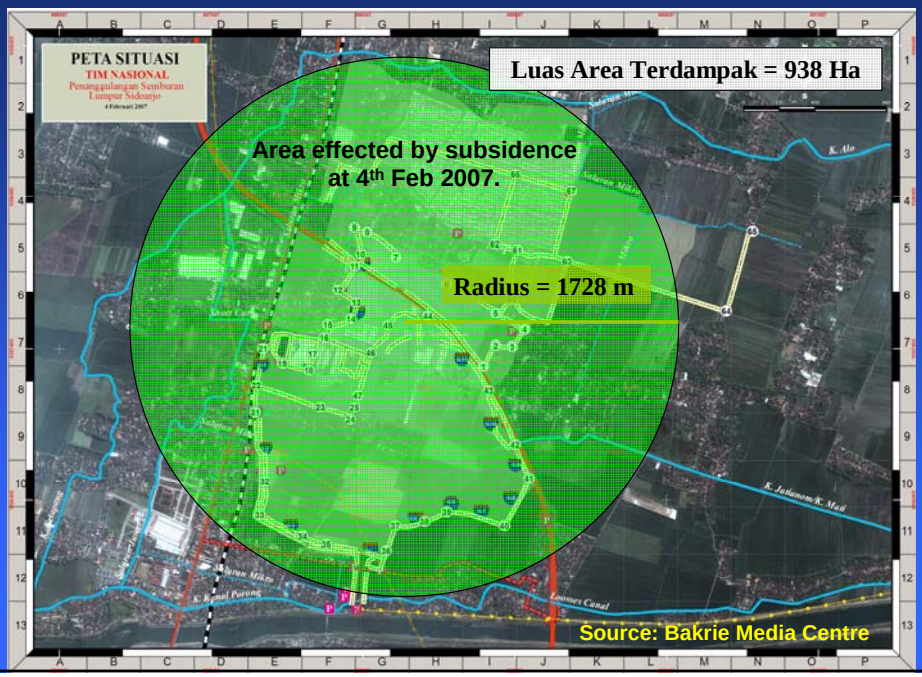
Photo: M. Tingay May 2007

How Long Could It Go On For?

- Lusi is unusual in that it has maintained a high flow rate for a long period of time.
- Mud volcanoes can last for 10's to hundreds of thousands of years.
- Internal blowout in Brunei lasted over 20 years (even with many relief wells).

Photo: M. Tingay May 2007

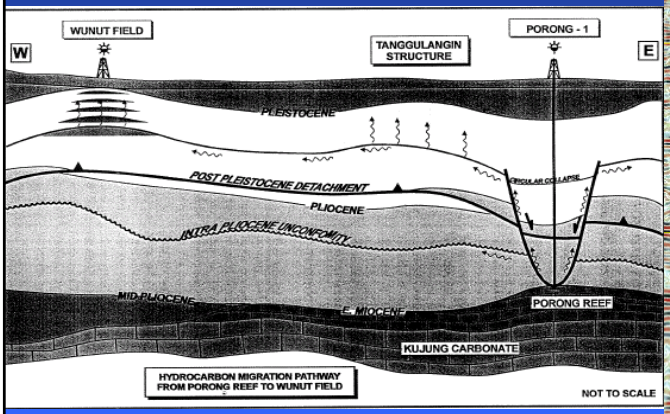
Future Problems: Ongoing Subsidence



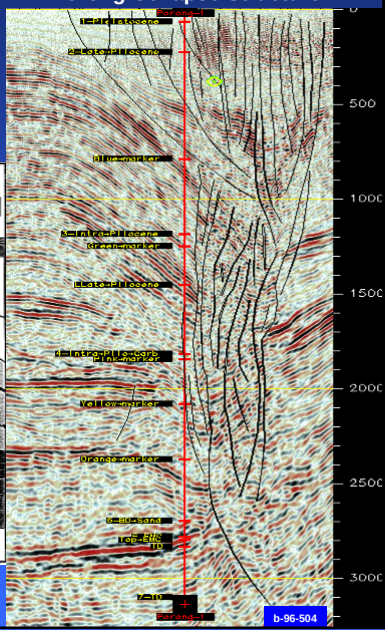
Potential for Caldera Collapse?

Collapse of the adjacent Porong structure just 7 km from Banjar Panji-1 – suggests similar eruption has occurred in last 0.5 Ma.

Similar collapse could be catastrophic in this densely populated area!



Seismic across 1km diameter Porong Collapse Structure



Sources: Seismic courtesy of Bakrie Media Centre; X-section from Kusumastuti et al. (1999).

Acknowledgements and Thanks:

Durham, UK: Dick Swarbrick and Richard Davies for discussions on Lusi eruption and on mud volcano systems worldwide.

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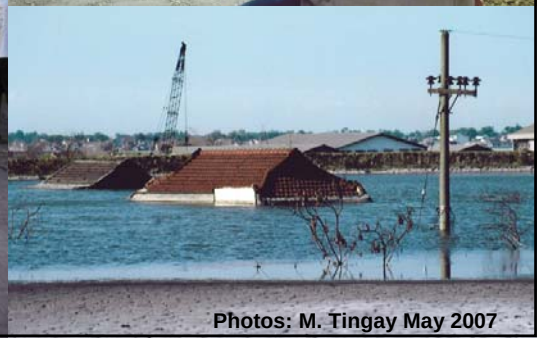
Photo: M. Tingay May 2007

Any Questions?



Photos: M. Tingay May 2007