The Lusi Mud Eruption of East Java*

Mark Tingay[1], Oliver Heidbach[2], Richard Davies[3], and Richard Swarbrick[4]

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Abstract

Early in the morning of the 29th of May 2006, hot mud started erupting from the ground in the densely populated Porong District of Sidoarjo, East Java. With initial flow rates of approximately 5000 cubic meters per day, the mud quickly inundated neighbouring villages. Over 18 months later and the 'Lusi' (coined from 'Lumpur Sidoarjo') eruption has increased in strength, expelling over 0.04 cubic kilometres of mud at rates of up to 170,000 cubic metres per day. The mud flow has now covered over 700 hectares of land to depths of up to 17 meters, engulfing eight villages and displacing over 17,000 people.

The Lusi eruption is an example of a mud volcano, a relatively common feature in sedimentary basins that have been rapidly deposited or are in tectonically active areas. However, Lusi provides an opportunity to study a large mud volcano from its birth and to investigate the origins, mechanics, and architecture of mobile shale features. This presentation will provide a summary of the Lusi mud volcano, review the events leading up to and following the eruption, and discuss the attempts made to contain and stop the mud flow.

Triggering of the Lusi mud eruption: Earthquake versus Drilling Initiation

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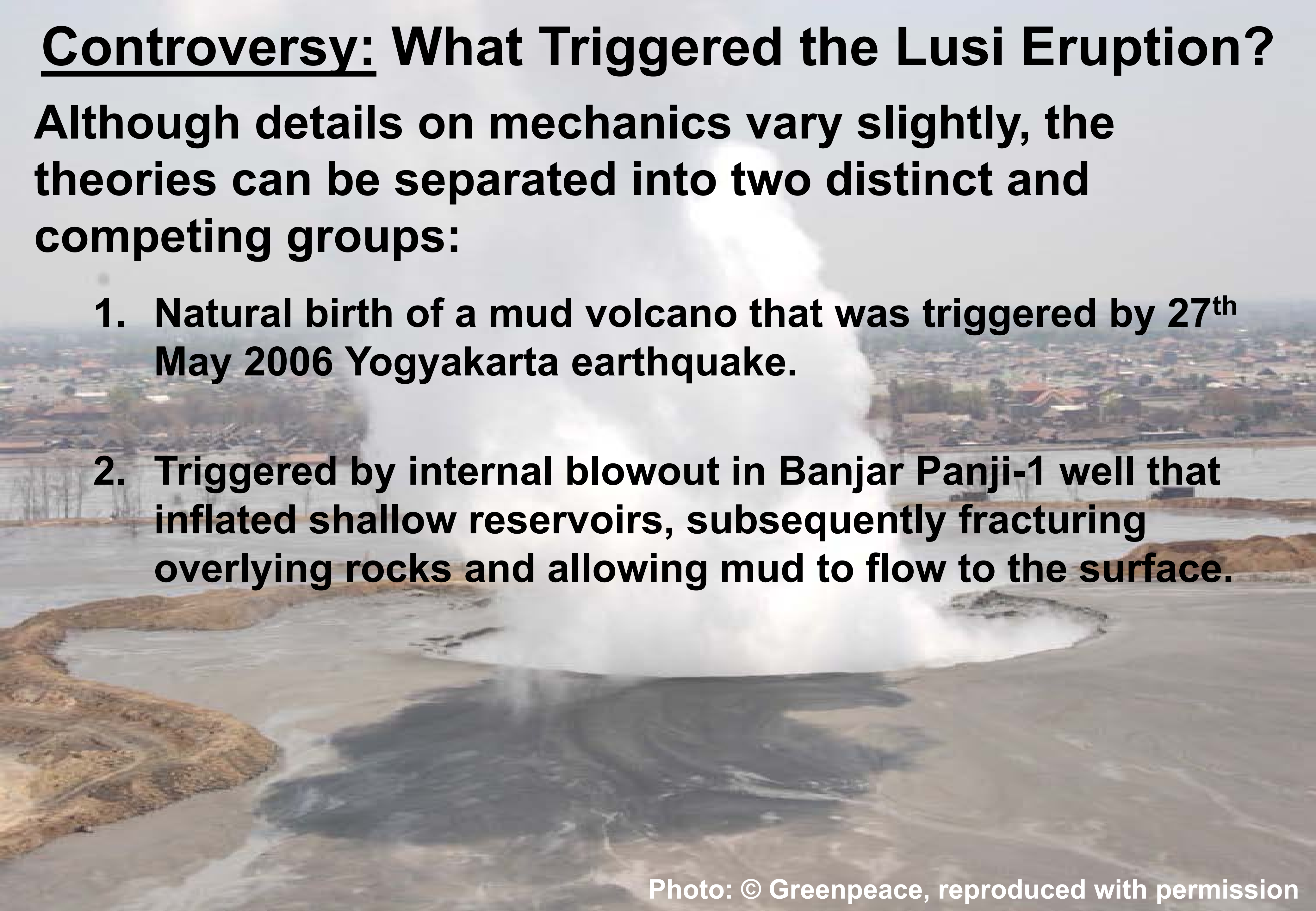
Photo courtesy Sidoarjo Mudflow Mitigation Agency

<u>Controversy:</u> What Triggered the Lusi Eruption?

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

1. **Natural birth of a mud volcano that was triggered by 27th May 2006 Yogyakarta earthquake.**

2. **Triggered by internal blowout in Banjar Panji-1 well that inflated shallow reservoirs, subsequently fracturing overlying rocks and allowing mud to flow to the surface.**



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The Lusi Mud Flow, East Java

- BACKGROUND
- EARTHQUAKE TRIGGERING HYPOTHESIS
- DRILLING TRIGGERING HYPOTHESIS
- CONCLUSIONS

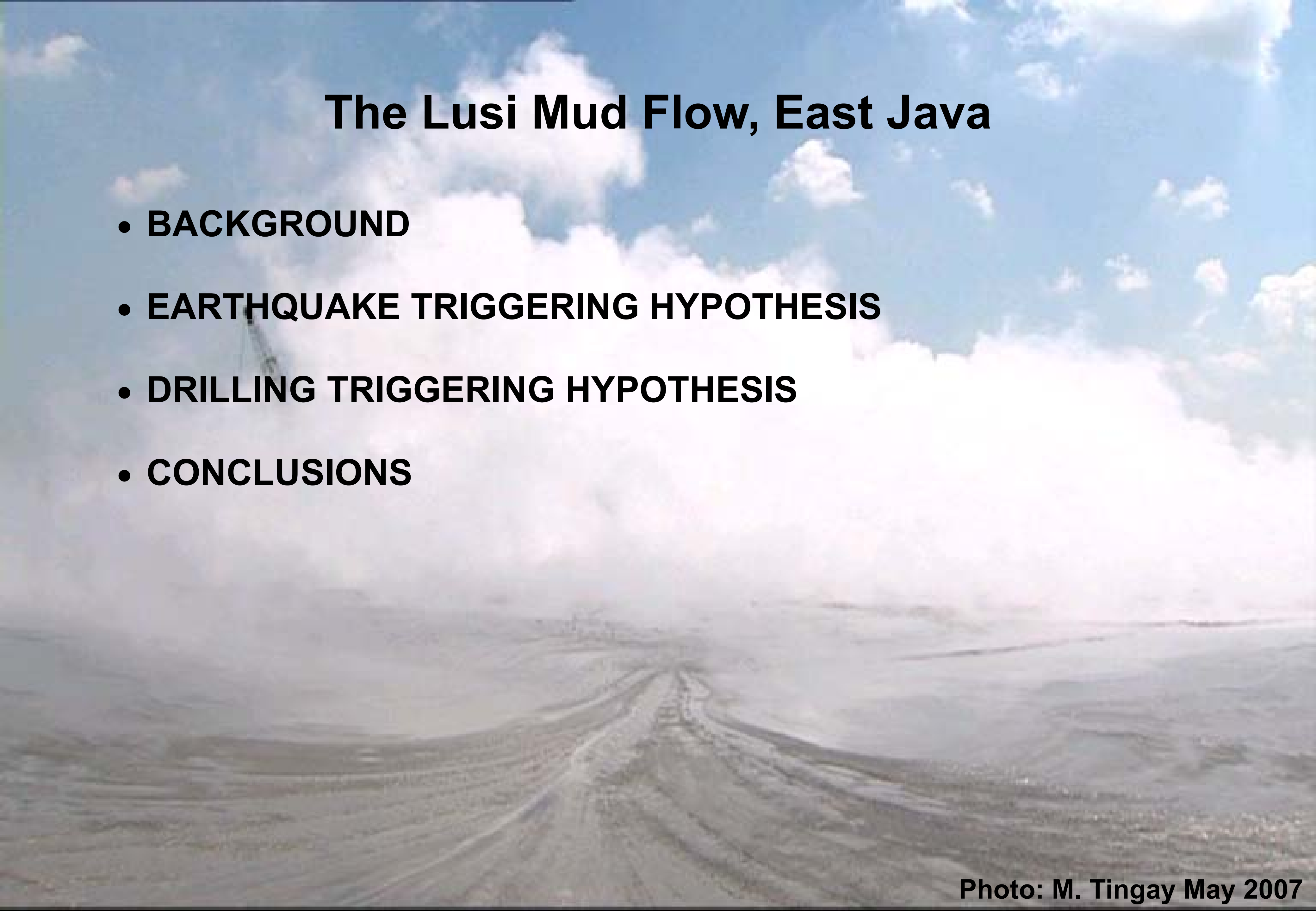

Photo: M. Tingay May 2007

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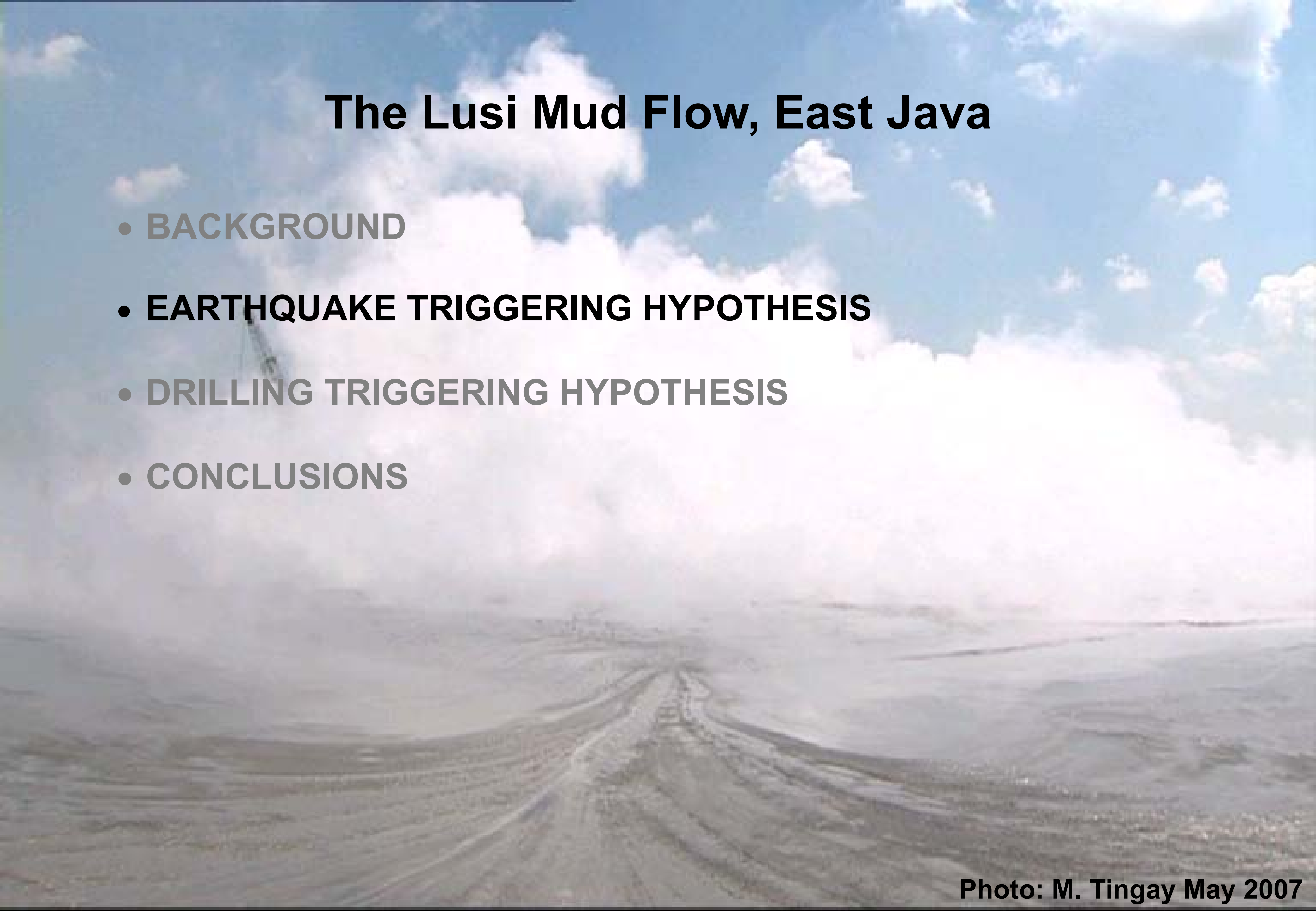


Photo: M. Tingay May 2007

Earthquake Trigger For Lusi?

• Yogyakarta (250km from Lusi) was shook by a Magnitude 6.3-6.4 earthquake two days prior to the eruption (~I-II intensity at Lusi).

• Earthquake occurred at 5.40am local time on the 27th of May 2006 (~2 days prior to Lusi initiation) and killed an estimated 6000 people.

• Theory: quake reactivated existing NE-SW oriented fault. Fault became permeable between 1200-3000 m depth, enabling overpressured fluids to entrain mud and escape to surface.

• Harris and Ripepe (JGR, 2007) observed that the Yogyakarta quake caused a 2-3 fold increase in heat flow from two igneous volcanoes, Merapi (50km from quake) and Semeru (300km from quake) in the 3-9 days after quake.

Evidence for Earthquake Eruption Trigger

- Many natural mud volcanos (e.g. Kalang Anyar) are within 50 km of Lusi.
- There is evidence of faulting following the eruption, suggesting fault triggered eruption (OR eruption triggered faulting!).
- There are examples of more proximal and higher magnitude earthquakes causing mud volcano eruptions offshore of Iran in 1945 (Makran earthquake) and 1999 (Malan Island; Kopf, 2002) and Azerbaijan (Mellors et al., 2007).
- Large earthquakes (>M7.5) have triggered fluid eruptions and liquifaction thousands of kilometres away (Husen et al., 2004).

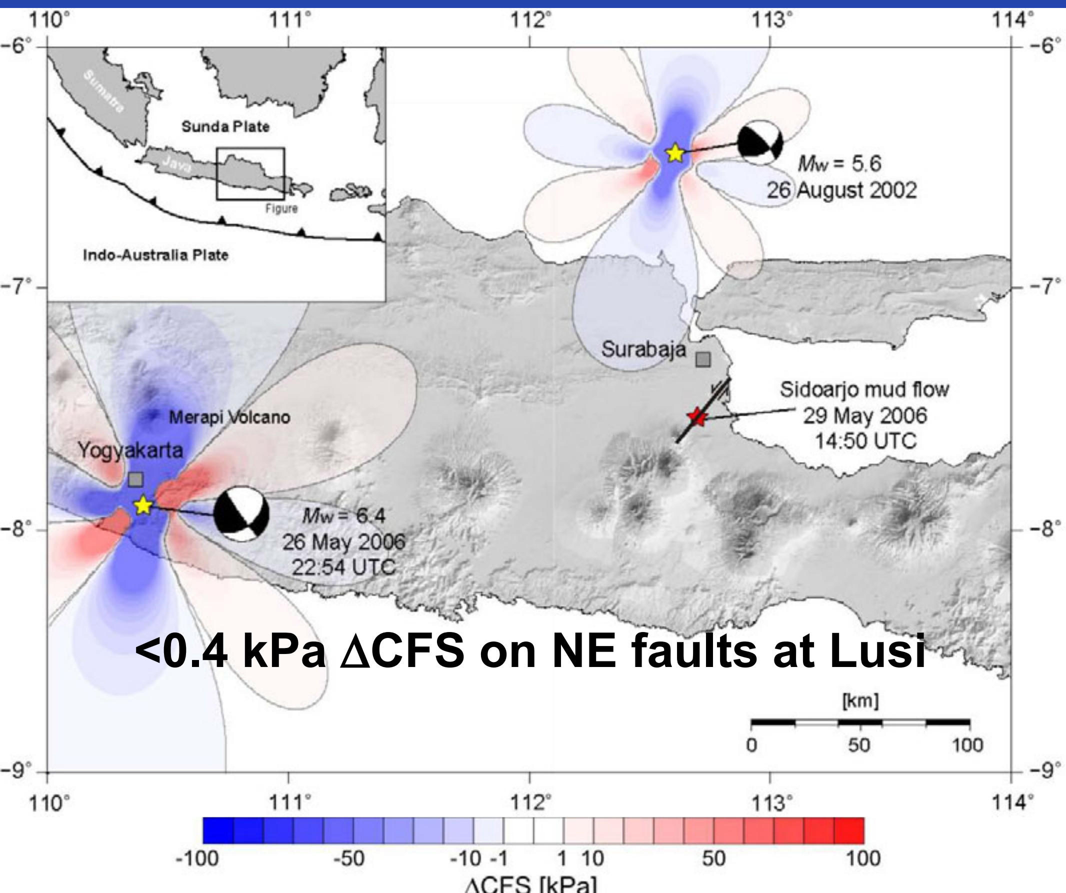

Kalang Anyar mud volcano

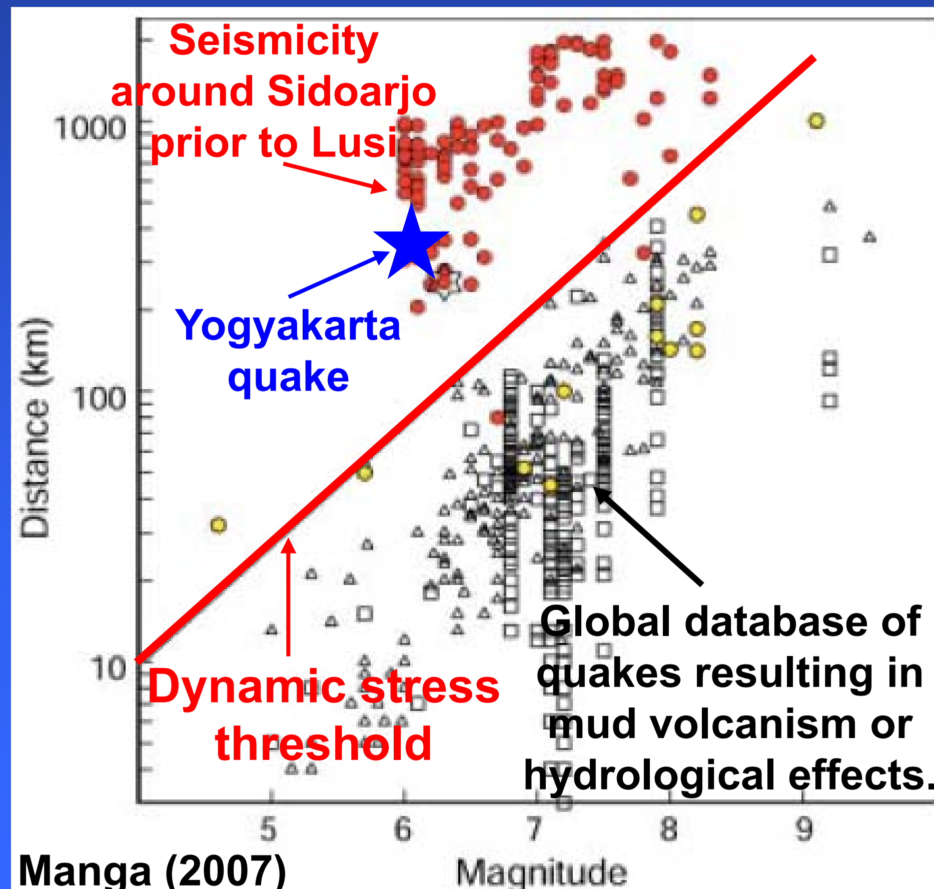

Photos: Lapindo Brantas
Sept 2006

Evidence against Earthquake Eruption Trigger

Yogyakarta earthquake was too small and/or far away to reactivate faults under Sidoarjo 250km away. Four processes for remote triggering of faults:

- co-seismically induced stress changes (e.g. ΔCFS); — Too small / far away (<0.4 kPa)
- post-seismic relaxation of static stress changes;
- poroelastic rebound effects, and; — Too far away & too slow (applies to both)
- dynamic stress changes due to seismic shaking. — Too small / far away (max 33 kPa)





Manga (2007)

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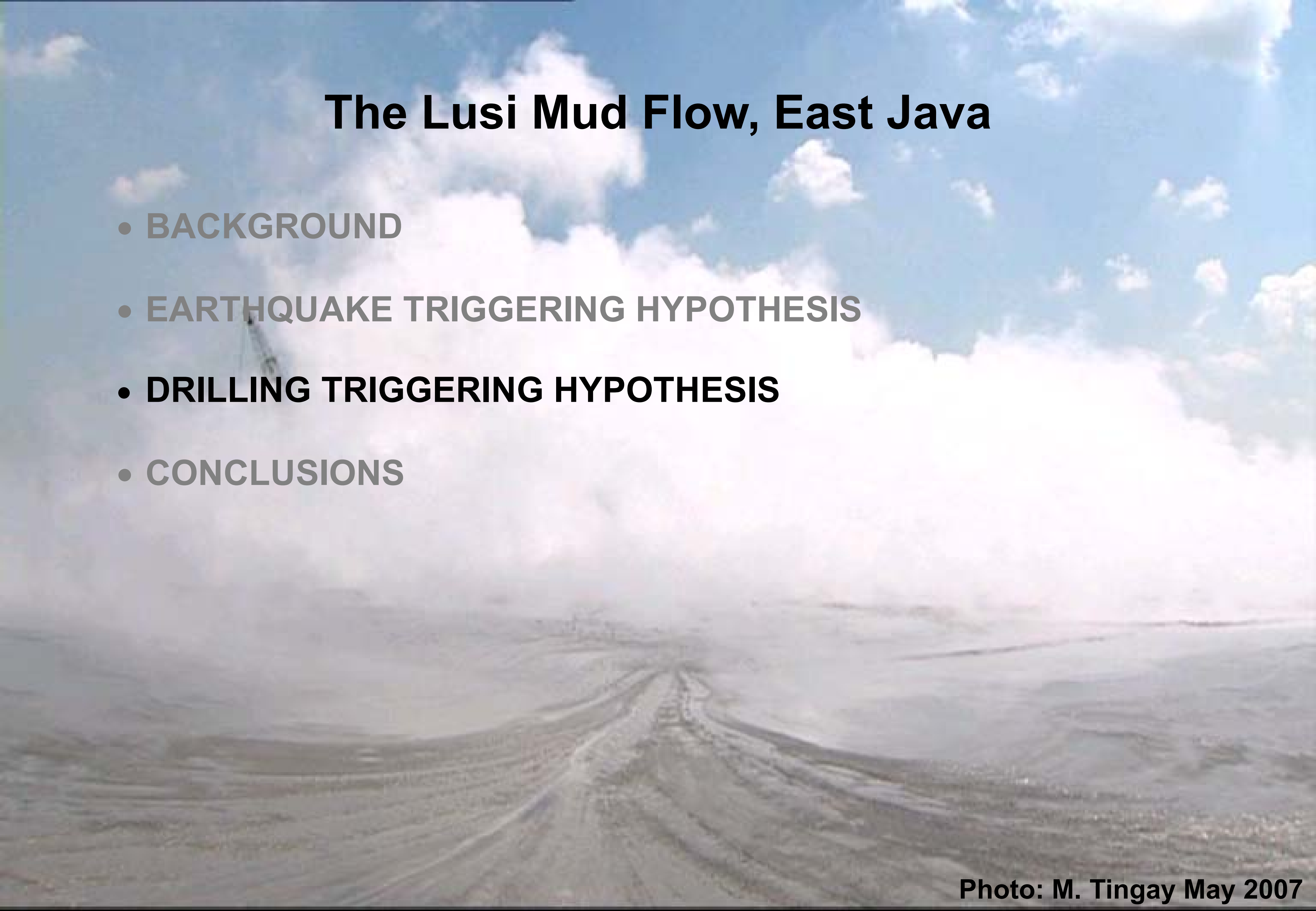
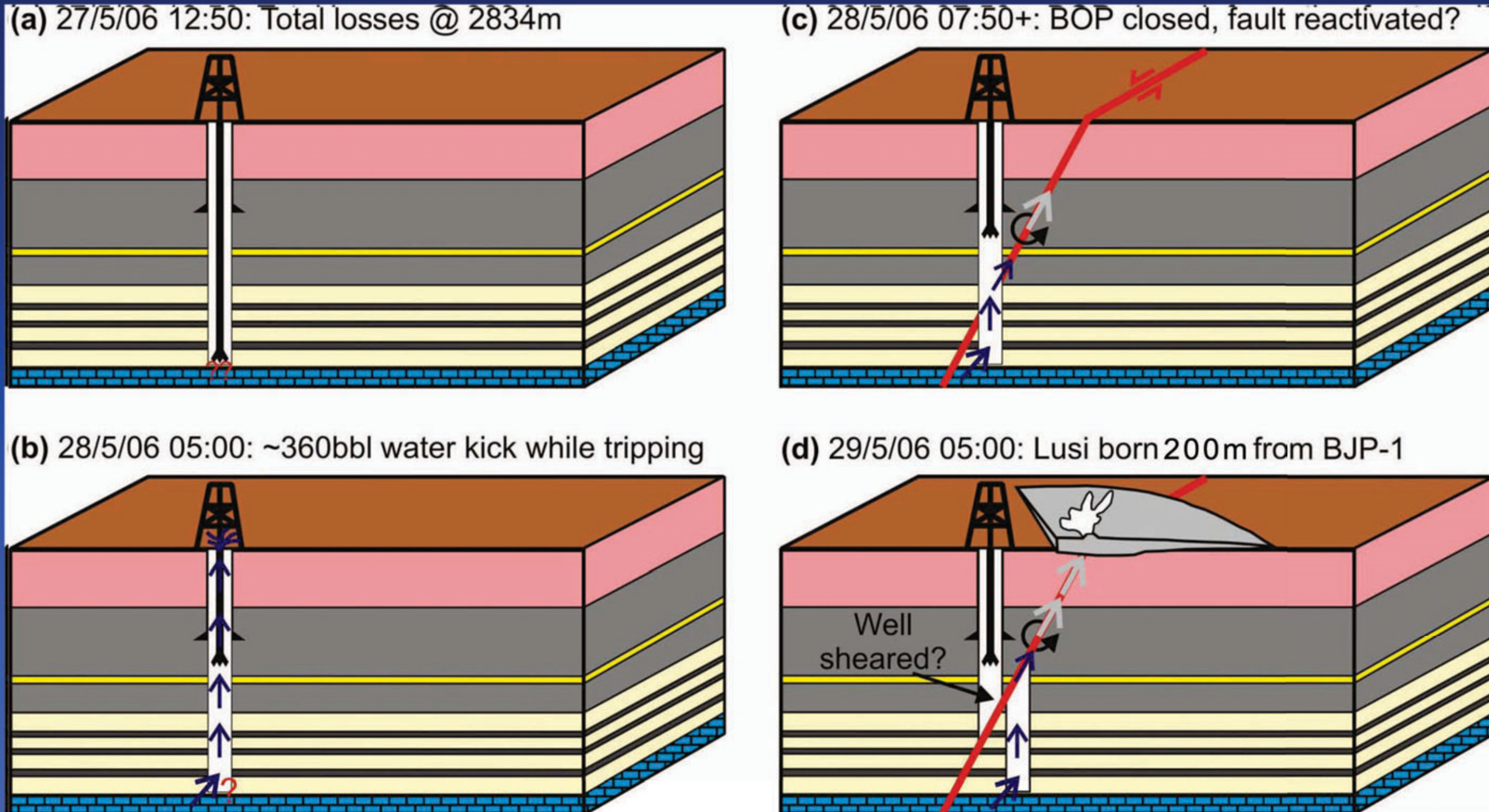


Photo: M. Tingay May 2007

Schematic Model for Drilling-Induced Triggering of Lusi



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

Modified from Davies et al., 2007, based upon Champion blowouts in Brunei (Tingay et al., 2005) and reports of other underground blowouts.

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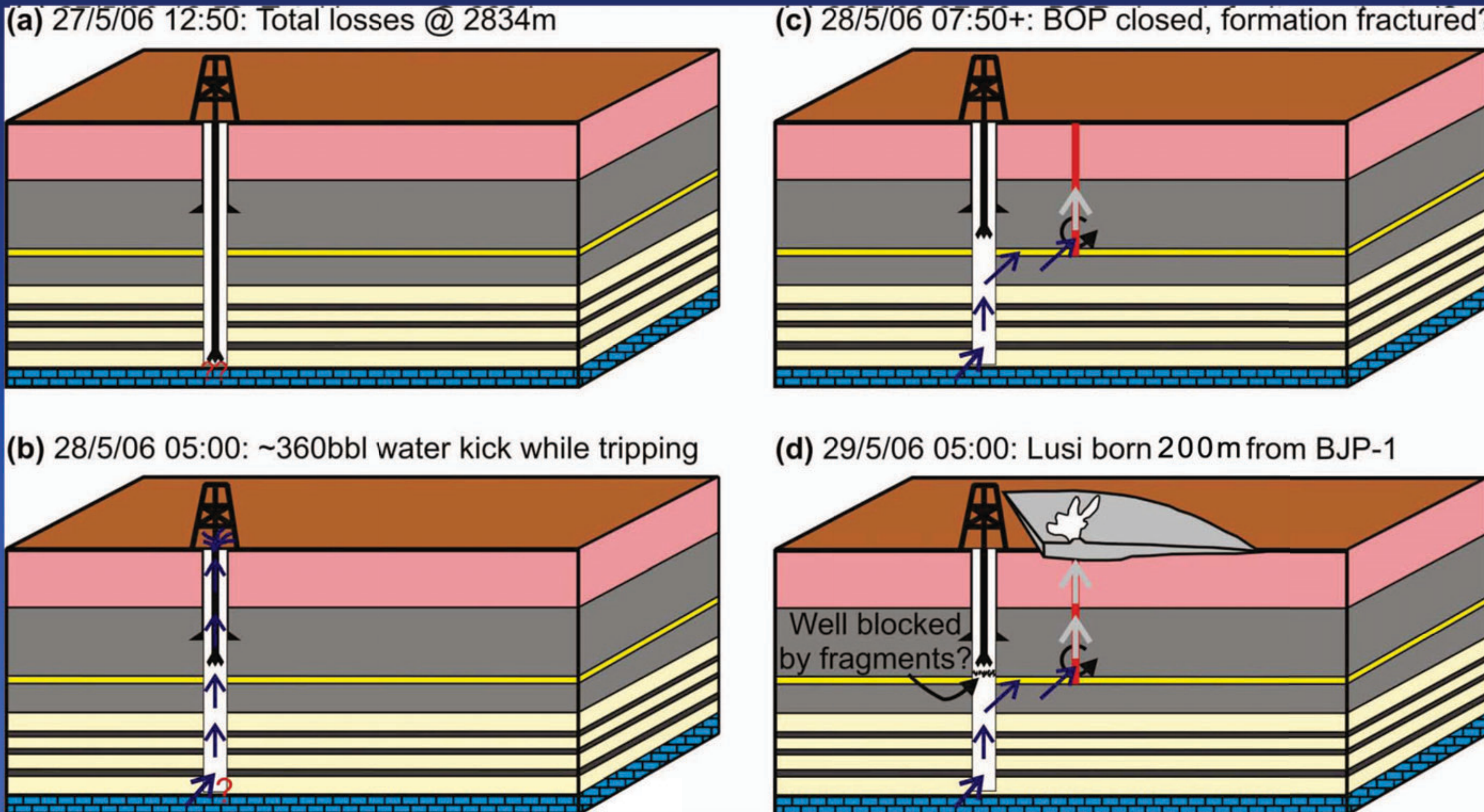

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Evidence for Drilling Trigger

- Banjar Panji-1 was being drilled 200m from Lusi eruption and suffered numerous drilling problems (kicks/losses) prior to Lusi eruption.

- Took a large kick 21 hours prior to Lusi eruption – between 62-95 m^3 (~360 barrels) of water and gas erupted at drill rig before well shut-in.

- Events following kick are unclear, but insufficient protective casing and narrow ‘kick tolerance’ suggest that development of underground blowout was likely.

- Wellbore pressures during kick interpreted to be large enough to fracture rocks and create fluid flow pathway to the surface.

- Sequence of losses/kicks, lack of casing and low kick tolerance is similar to conditions prior to other blowout-triggered eruptions (Champion Field Brunei, Platform A Santa Barbara).

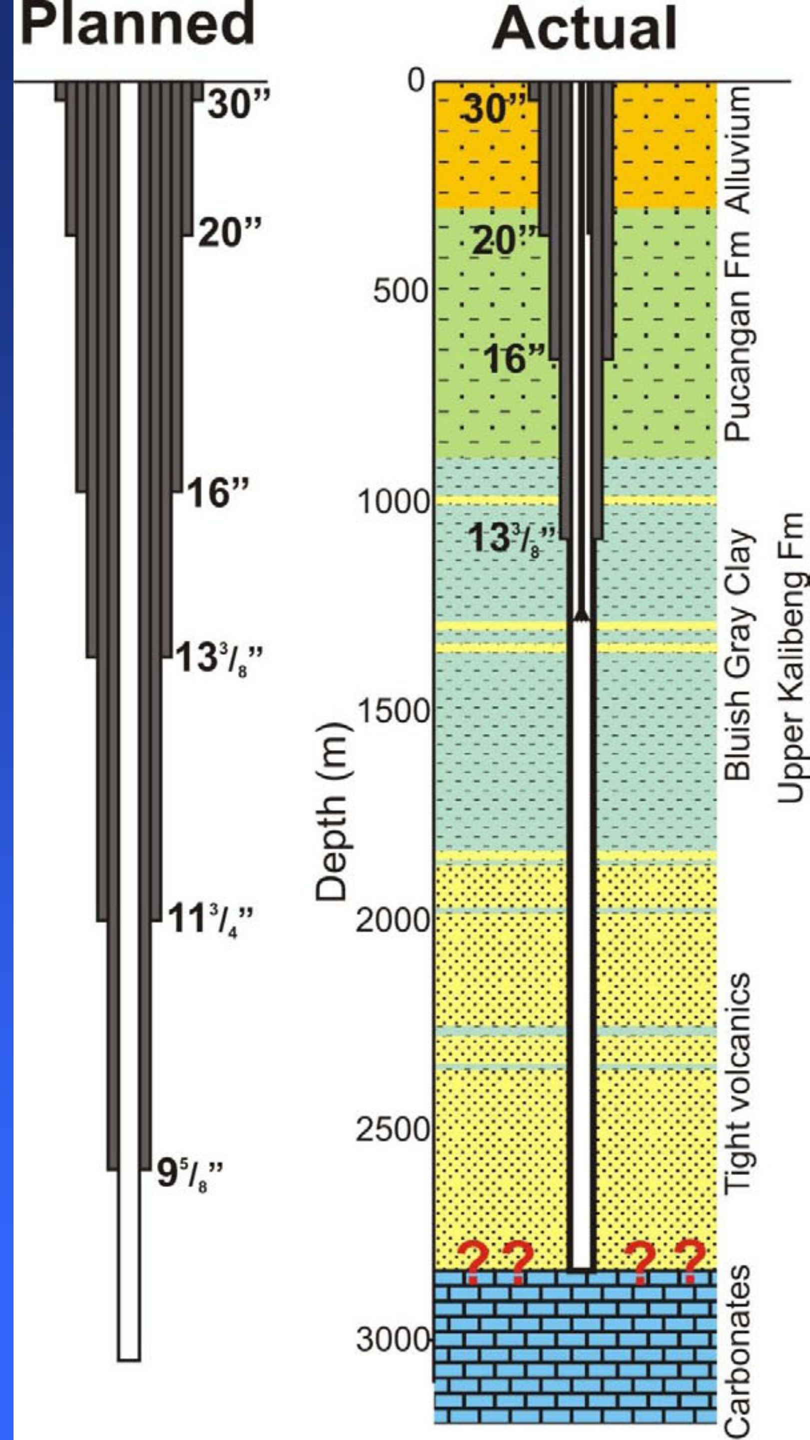
- Formation of non-eruptive cracks between Lusi and the drill site on first day of eruption – indicates subsurface fluid flow between well and Lusi.

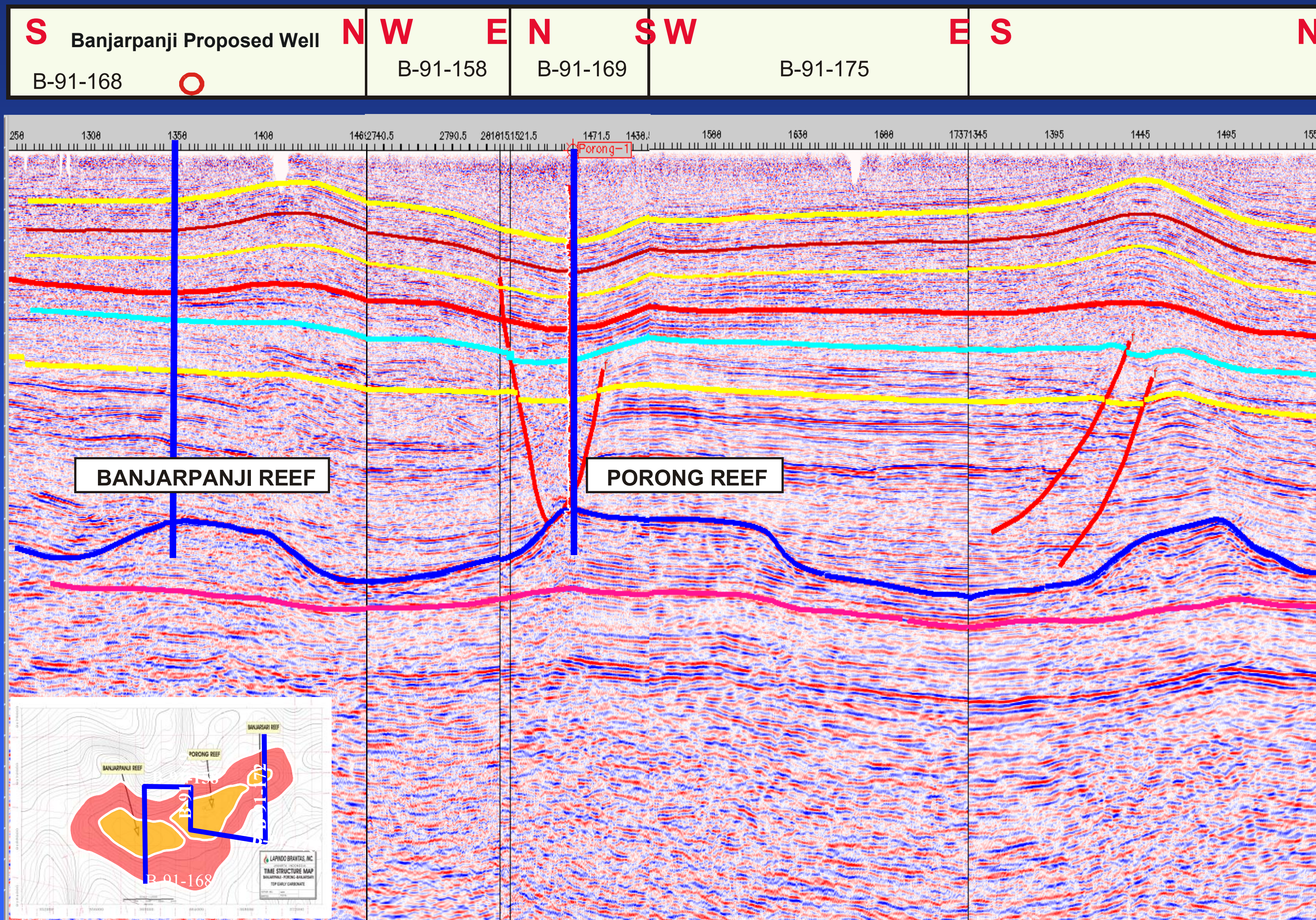
Photo: Sidoarjo Mudflow Mitigation Agency

Sources: Davies et al., 2007; Mazzini et al., 2007; Sutriono, 2007; Davies et al., 2008; Tingay et al., 2008.

Planned versus Actual Casing Design in Banjar Panji-1

- Banjar Panji-1 planned to have six casing points <610m (<2000') apart.
- Losses and stability issues resulted in the 16" and 13 3/8" casing points being set shallower than planned.
- Planned 11.75" casing point skipped and 9 5/8" casing point postponed.
- 9 5/8" casing planned to be set inside carbonates – despite 15.8-17 ppg seen in Porong carbonates 7 km away.
- Resulted in a total of 1742 m of open hole section (1091-2833 m) existing prior to complete losses and kick on the 27th/28th May.

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Banjarpanji Proposed Well
N
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B-91-158
N
S
B-91-169
W
E
B-91-175
S
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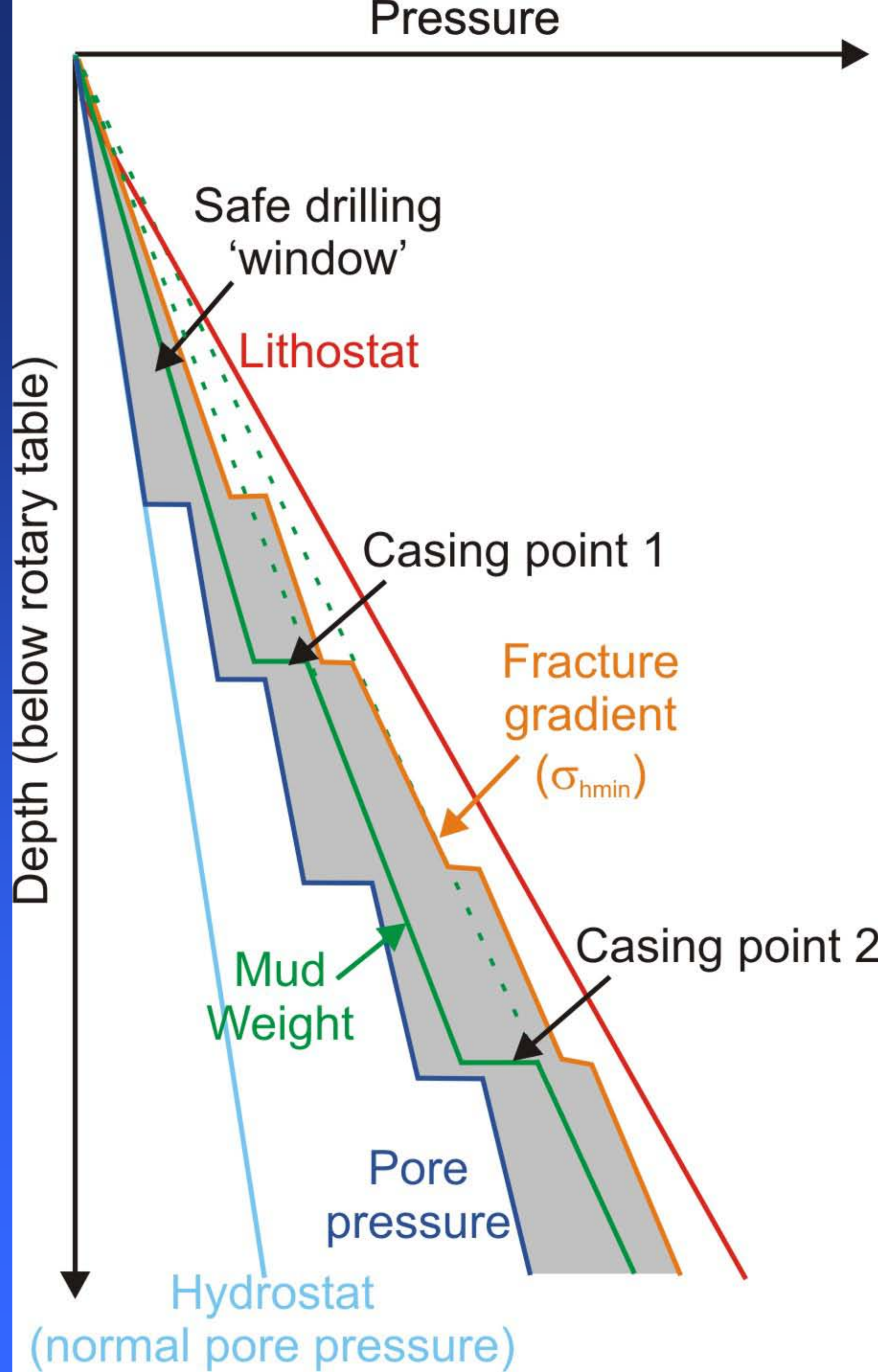
Porong-1
BANJARPANJI REEF
PORONG REEF
B-91-168

Why Set Casing?

- Mud weight must be maintained between pore pressure and fracture pressure – known as the ‘safe drilling window’ or ‘kick tolerance’.

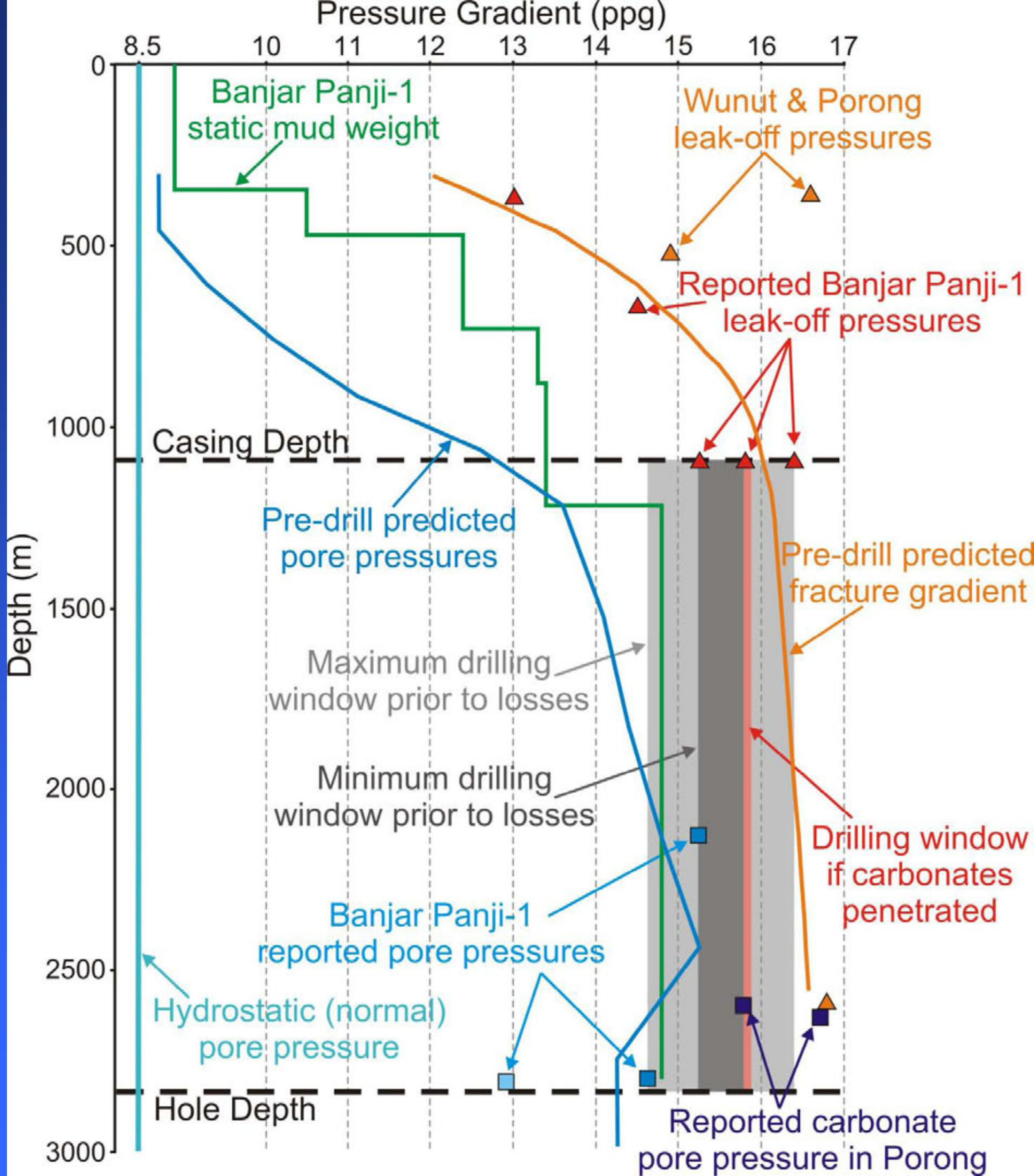
- Casing is set to strengthen upper section of hole and allow higher mud weight to be run.

- Major internal blowouts often occur when drilling window ‘closes’ – mud weight cannot be balanced to prevent kicks and losses.



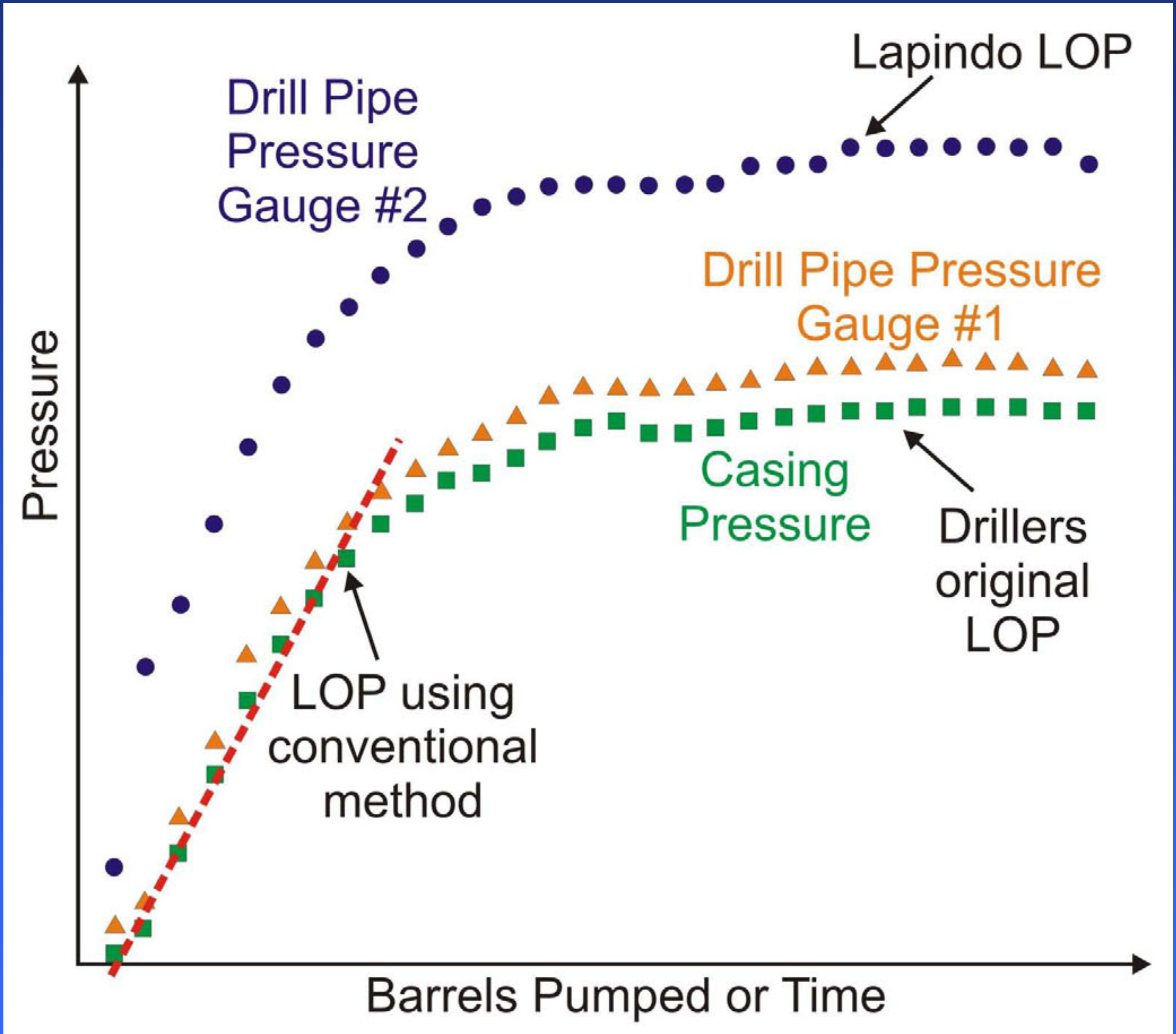
Internal Blowout in Banjar Panji-1?

- Narrow drilling window in uncased section (≤1.8 ppg).
- However, pore pressure and fracture pressure reports vary: drilling window may have been only 0.05 ppg!
- Drilling window <0.6 ppg if carbonates encountered.
- Hence, drilling window at casing shoe was 10-333 psi wide prior to kick.
- Annulus pressures after BOP was closed were sufficient to fracture the wellbore.
- Lapindo reports 12.8 ppg BHP: gives window of 466-666 psi.



Data uncertainty example: Schematic of LOT at 1091m

- All Lusi data is uncertain to varying degrees!
- Three estimates of the critical LOP at 1091m casing point.
- LOP typically quoted is 200 psi higher than LOP calculated by conventional method.
- Furthermore, LOP is an _overestimate_ of minimum pressure that formation can fracture.
- Hence, safe drilling practices suggest using lowermost LOP values.



Evidence Against Drilling Trigger

- Pore pressures in open hole section and deep carbonates poorly constrained or unknown – no direct accurate pressure tests were taken.
- There are lots of confusion and uncertainty over events following major kick – the drilling data can be interpreted in a variety of ways.
- Drilling data only provides information at bit (stuck at 1293m) and casing shoe (1091m) – nothing is known about what took place in well below the bit.
- Reports indicate that well was re-opened, could have been circulated several hours and weeks after kick – not typical of blowout, though well was plugged!
- Flow rates of >100000 m^3 per day are thought to be greater than what can be achieved through a 12.25” borehole, though are reported in other blowouts.
- Attempts to kill mud eruption by injecting high density fluid into well failed, though possibly reduced rate of mudflow.
- It is not known whether the deep carbonate formation was penetrated or whether these are the primary source of water for the mudflow.

Photo: Mark Tingay, May 2007

Sources: Davies et al., 2007; Mazzini et al., 2007; Sutriono, 2007; Davies et al., 2008; Tingay et al., 2008.

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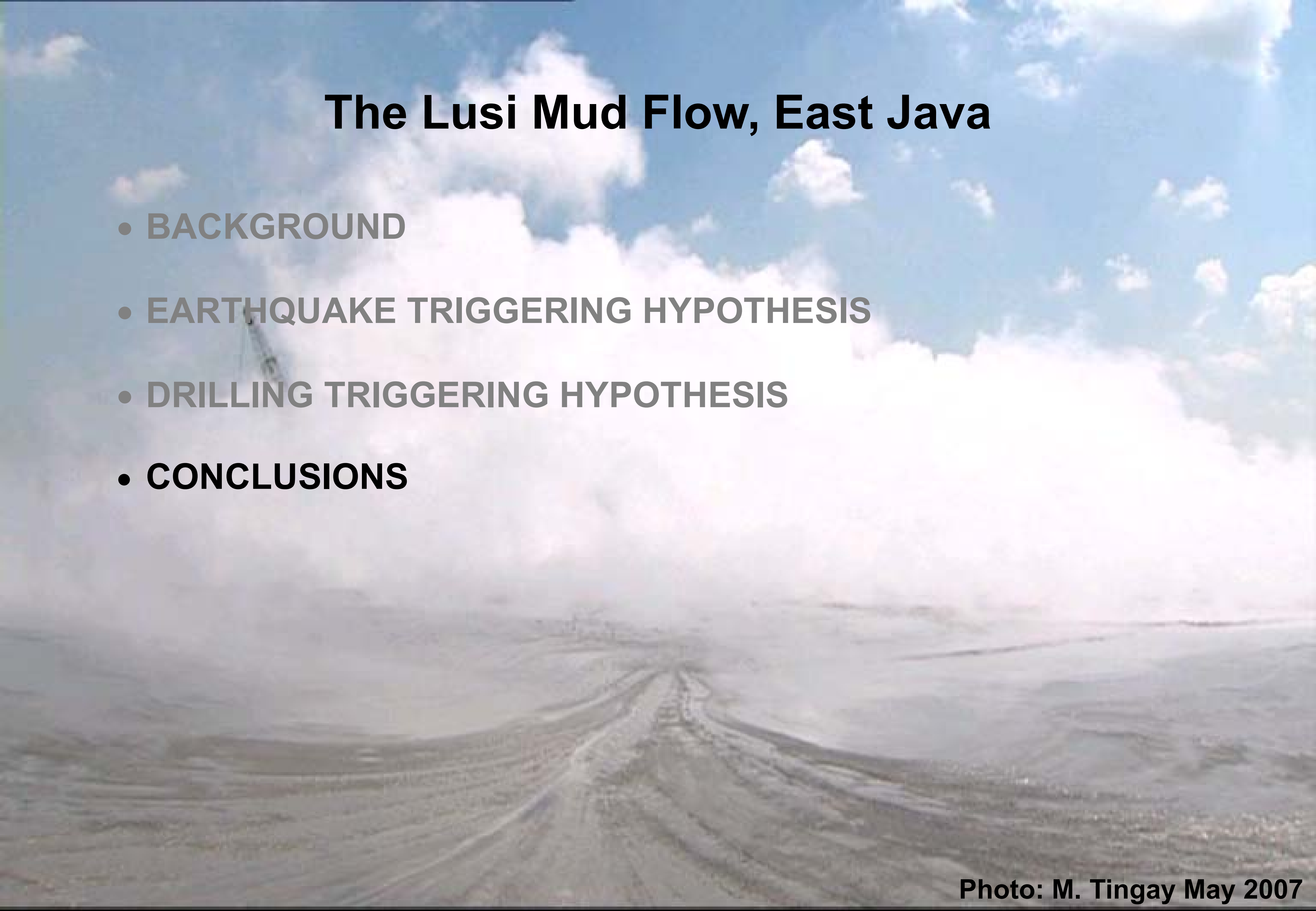


Photo: M. Tingay May 2007

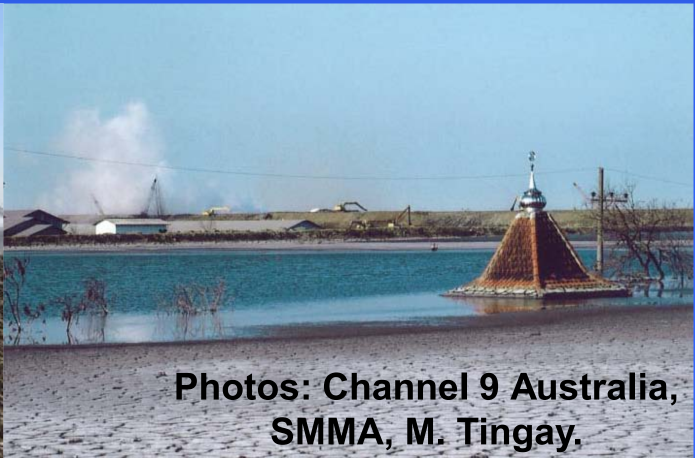
Conclusions

- The Lusi mudflow is a unique geological disaster that has displaced ~40000 people and threatens ~100000 more people (~US$450 million damage bill).

- Data uncertainties remain and interpretations vary - trigger for the Lusi mud eruption may never be conclusively (i.e. zero doubt) proven.

- Yogyakarta earthquake occurred 2 days prior to eruption – but quake was an order of magnitude too small to have triggered the mudflow.

- Banjar Panji-1 well was being drilled at high risk of blowout (insufficient casing, low drilling window/kick tolerance) and experienced numerous drilling problems, including a major kick that was potentially sufficient to fracture formation – hence, drilling trigger is mechanically possible, fits evidence and is most likely.



Photos: Channel 9 Australia, SMMA, M. Tingay.

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Thanks to Howard Sacre (**60 Minutes, Channel 9 Australia**) and Grace Duran (**Greenpeace**) for photos of Lusi.

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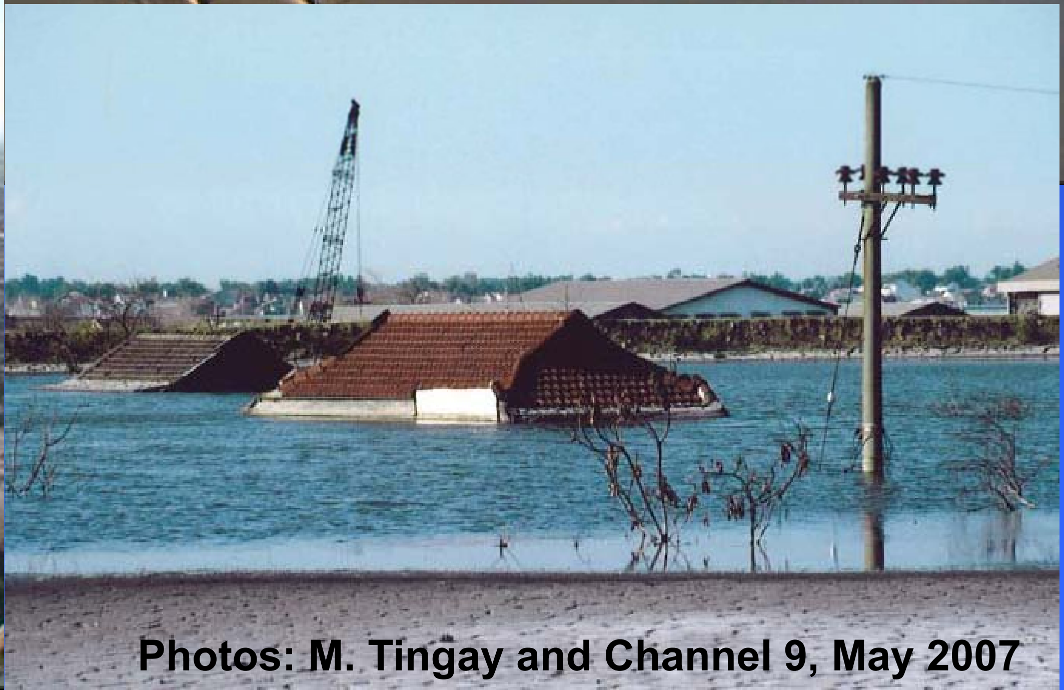
Any Questions?



Photos: M. Tingay and Channel 9, May 2007

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