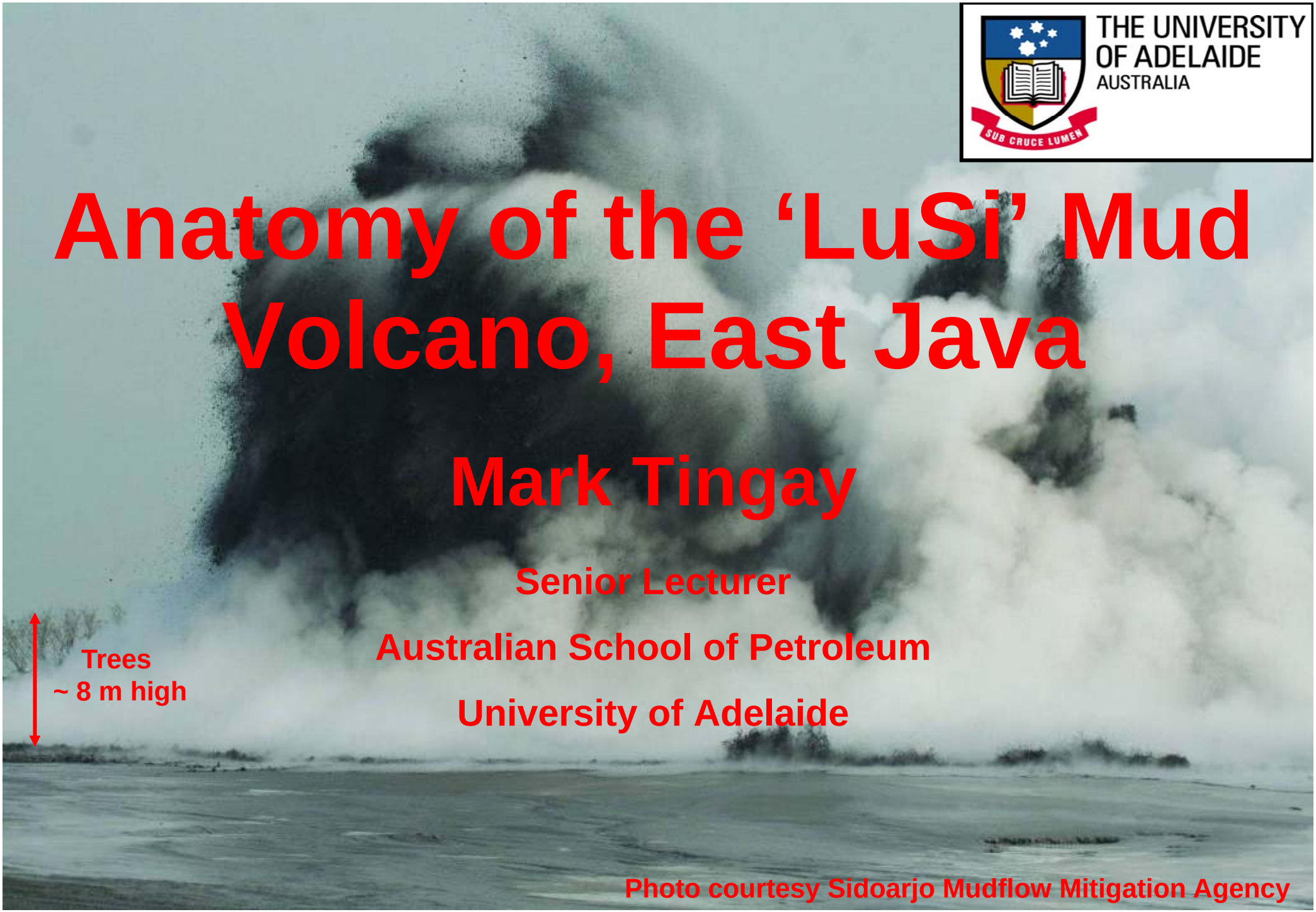

Anatomy of the 'LuSi' Mud Volcano, East Java

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THE UNIVERSITY OF ADELAIDE AUSTRALIA

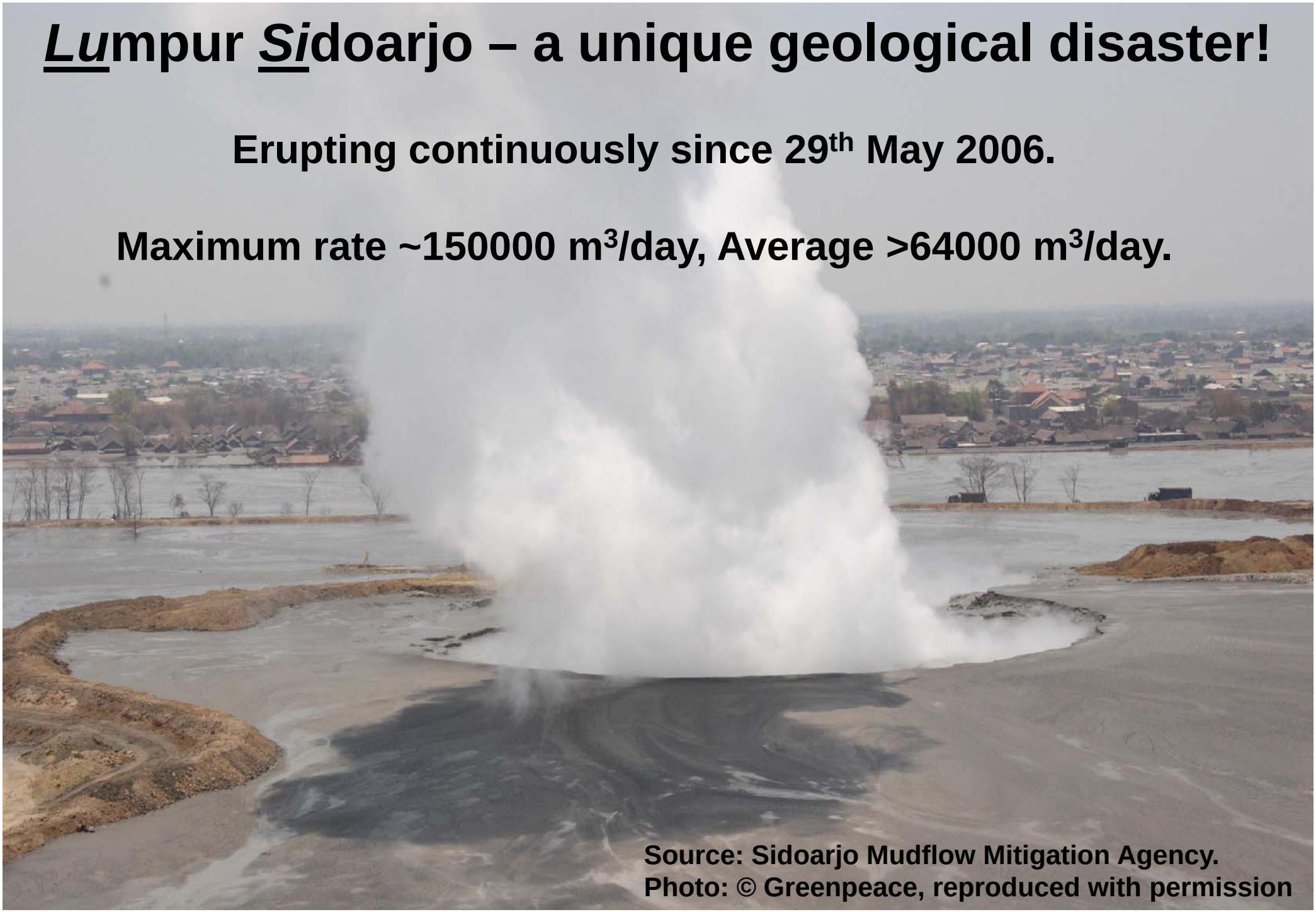
SUB CRUCE LUMEN

Photo courtesy Sidoarjo Mudflow Mitigation Agency

*Lu*mpur *Si*doarjo – a unique geological disaster!

Erupting continuously since 29th May 2006.

Maximum rate ~150000 m^3/day, Average >64000 m^3/day.



Source: Sidoarjo Mudflow Mitigation Agency.
Photo: © Greenpeace, reproduced with permission

Displaced ~40000, 12 villages, >10000 homes, ~100 schools, factories & mosques, >US$500 million in damage and clean up.

Source: Sidoarjo Mudflow Mitigation Agency, Mazzini et al., 2007, Time Asia 2008, Java Post.

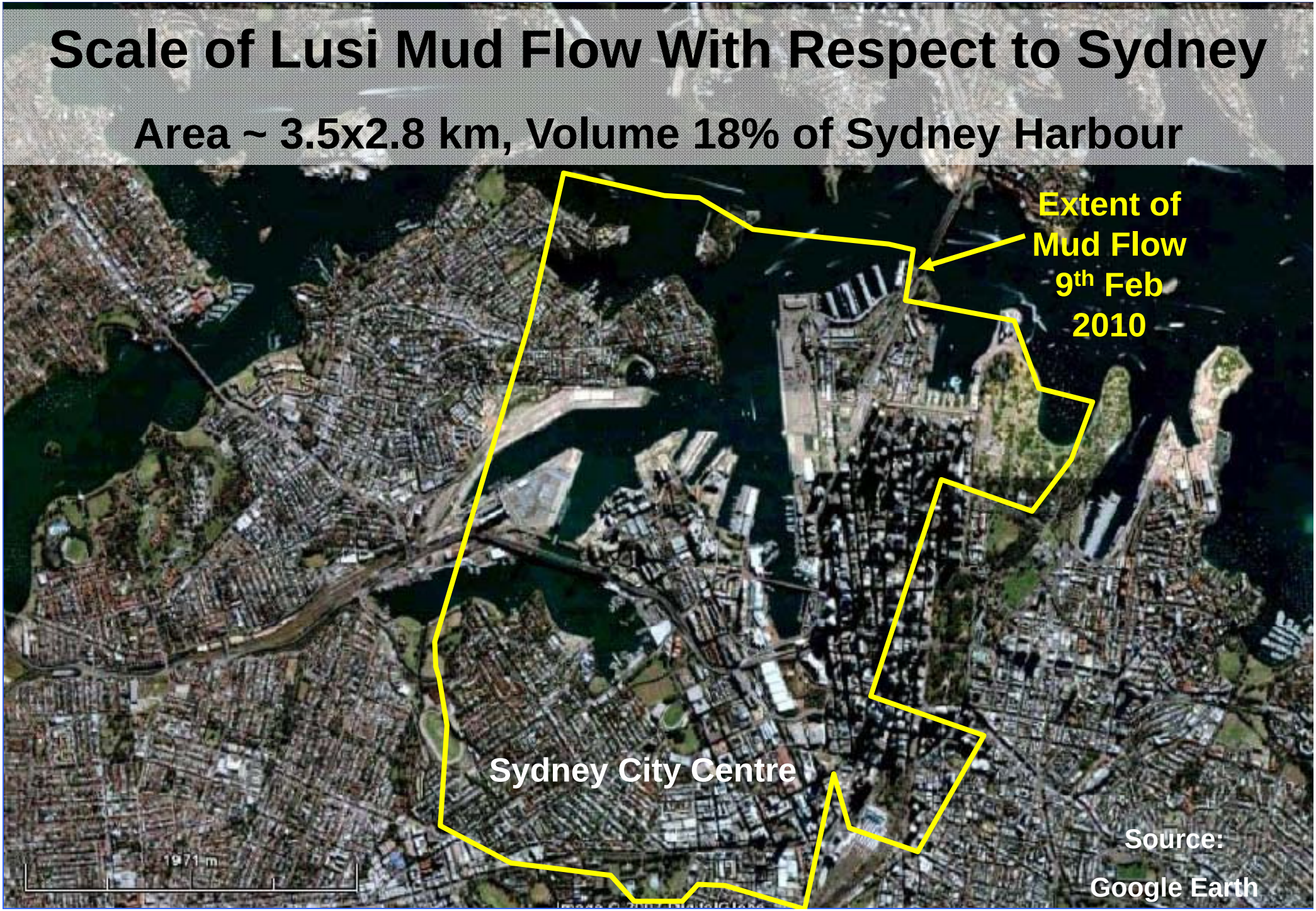
Photos: M. Tingay and Channel 9 Australia, May 2007

Mud has covered area of ~10 km^2 contained within series of dams.

Total mud erupted is >0.095 km^3 (95 million m^3) at an average rate of ~64000 m^3 per day

Scale of Lusi Mud Flow With Respect to Sydney

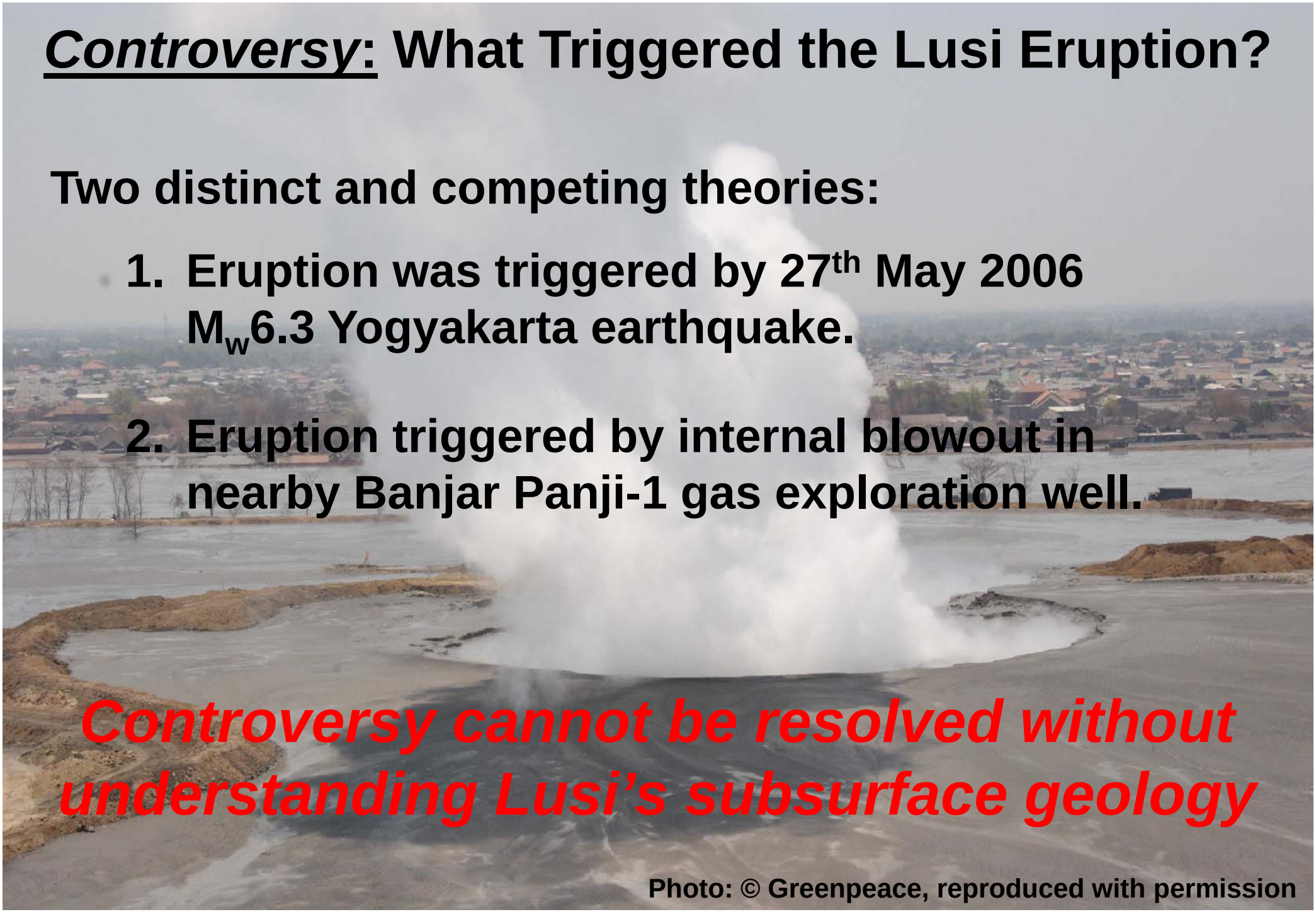
Area ~ 3.5x2.8 km, Volume 18% of Sydney Harbour



Video Footage of the Lusi Eruption Area

August-Sept 2006, © Greenpeace, shown with permission

***Controversy*: What Triggered the Lusi Eruption?**



Two distinct and competing theories:

1. **Eruption was triggered by 27th May 2006 M_w6.3 Yogyakarta earthquake.**

2. **Eruption triggered by internal blowout in nearby Banjar Panji-1 gas exploration well.**

Controversy cannot be resolved without understanding Lusi's subsurface geology

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- NEW INFORMATION ON SUBSURFACE GEOLOGY
- IMPLICATIONS AND SUMMARY

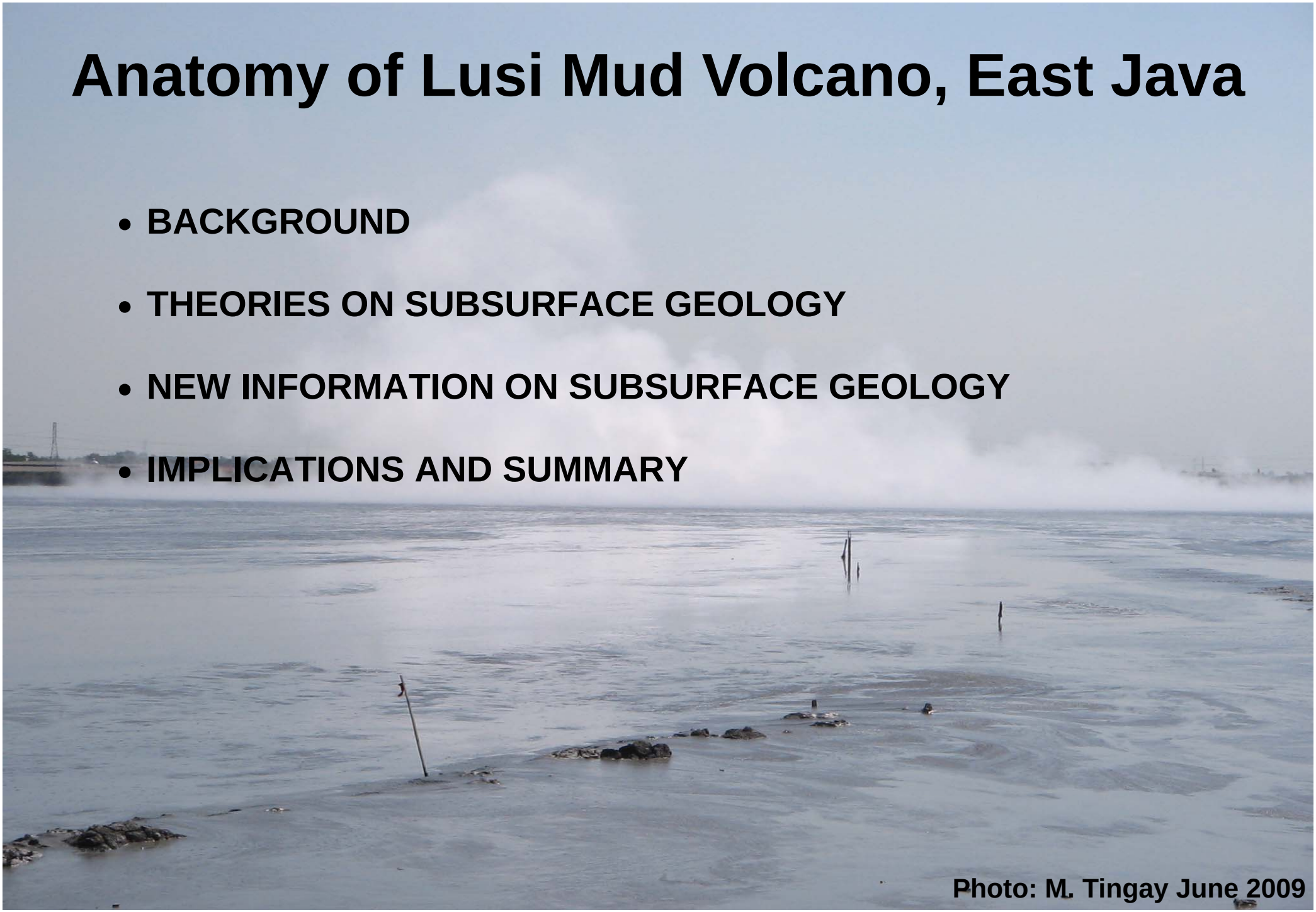

Photo: M. Tingay June 2009

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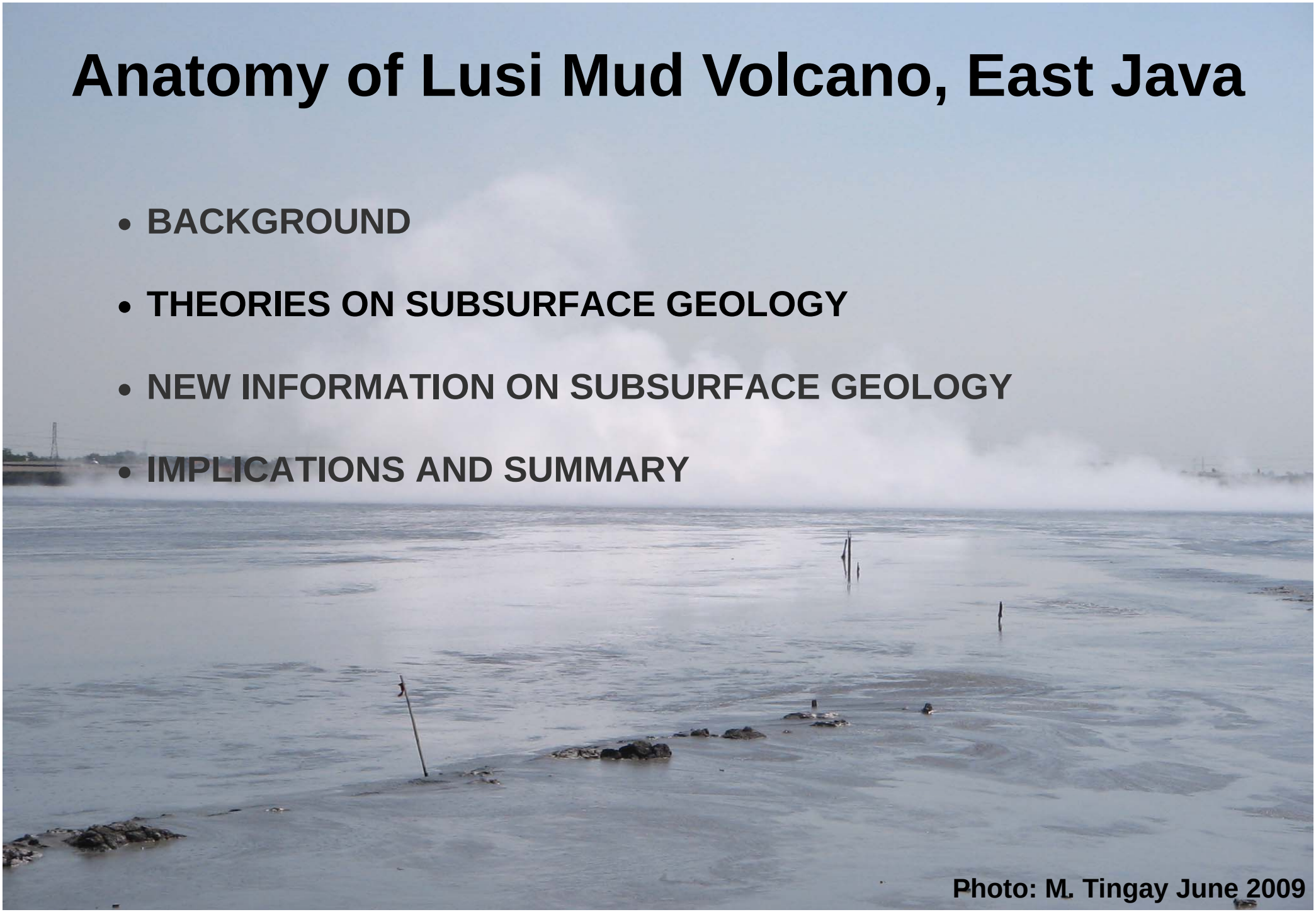


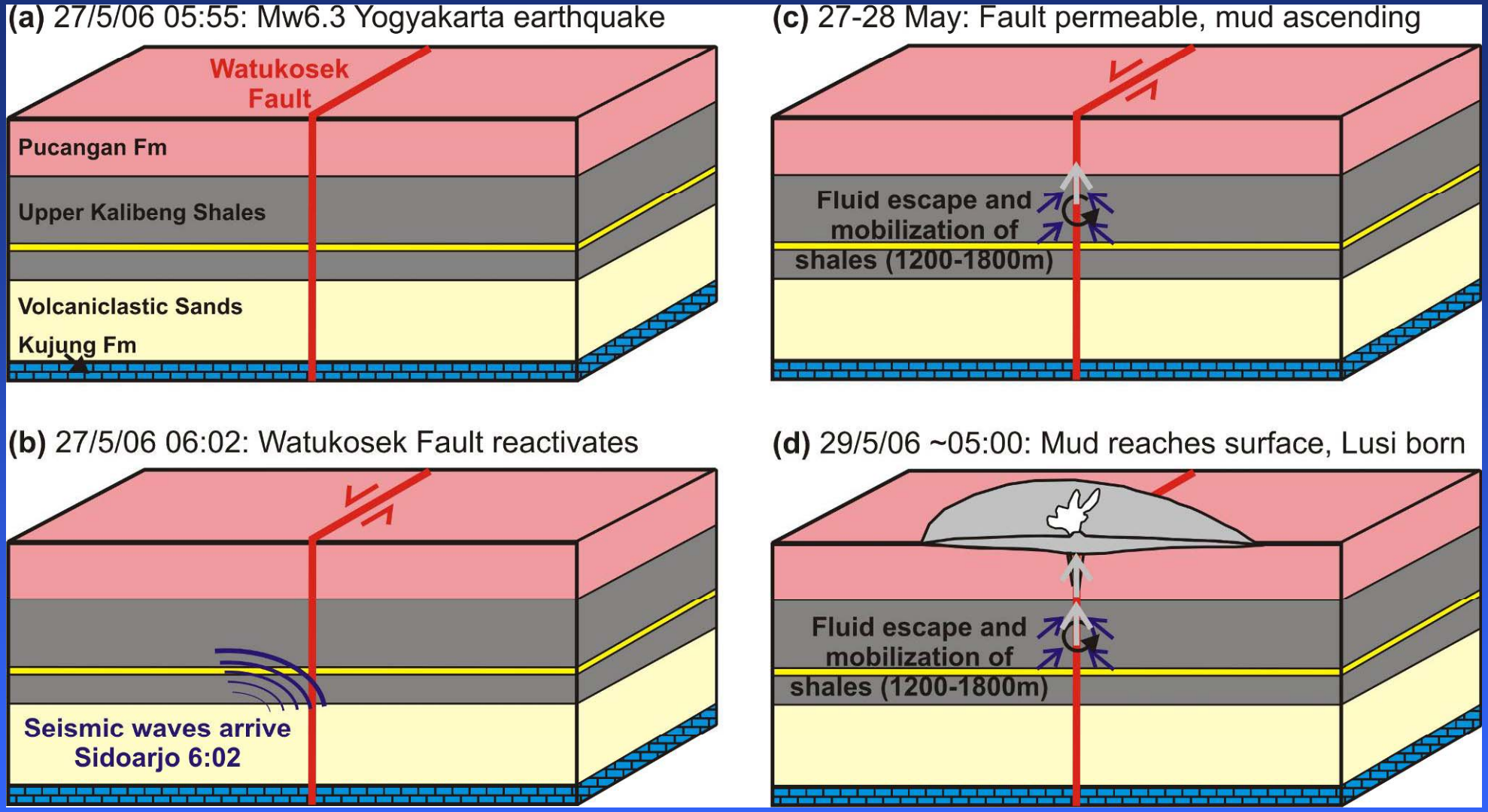
Photo: M. Tingay June 2009

WHAT DO WE KNOW ABOUT LUSI?

- **Solid fraction (clay) is predominately from Pleistocene Upper Kalibeng shales (1200-1800m).**
- ***Water origin unknown*, temp/chem suggests >1700m.**
- **Migration pathway originally along NE-SW fault (Watukosek?), later reactivation of NW-SE fault.**
- **Limited geology from Banjar Panji-1 well.**
- **Pre-existing and subsequent structure poorly understood (poor seismic, difficult to do geophysics).**

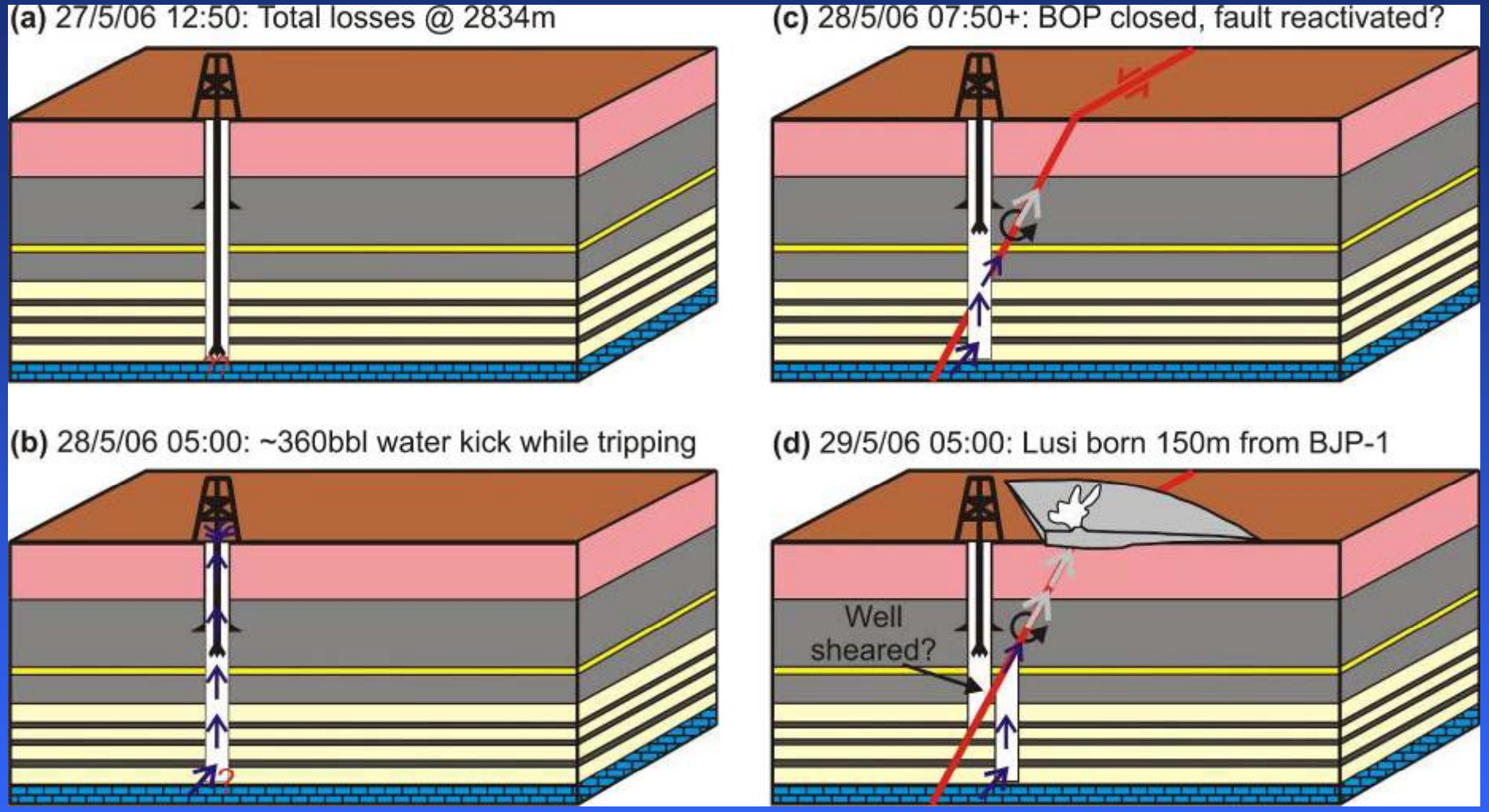
Uncertainty in water origin and subsurface geology leads to two models for Lusi based on different triggering theories.

Schematic Model for Earthquake Triggering of Lusi



Earthquake trigger theory suggests Lusi result of **remote reactivation** of Watukosek fault. Seismic shaking caused reactivation, mobilization (& liquefaction?) of Kalibeng Shales.

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 other underground blowouts.

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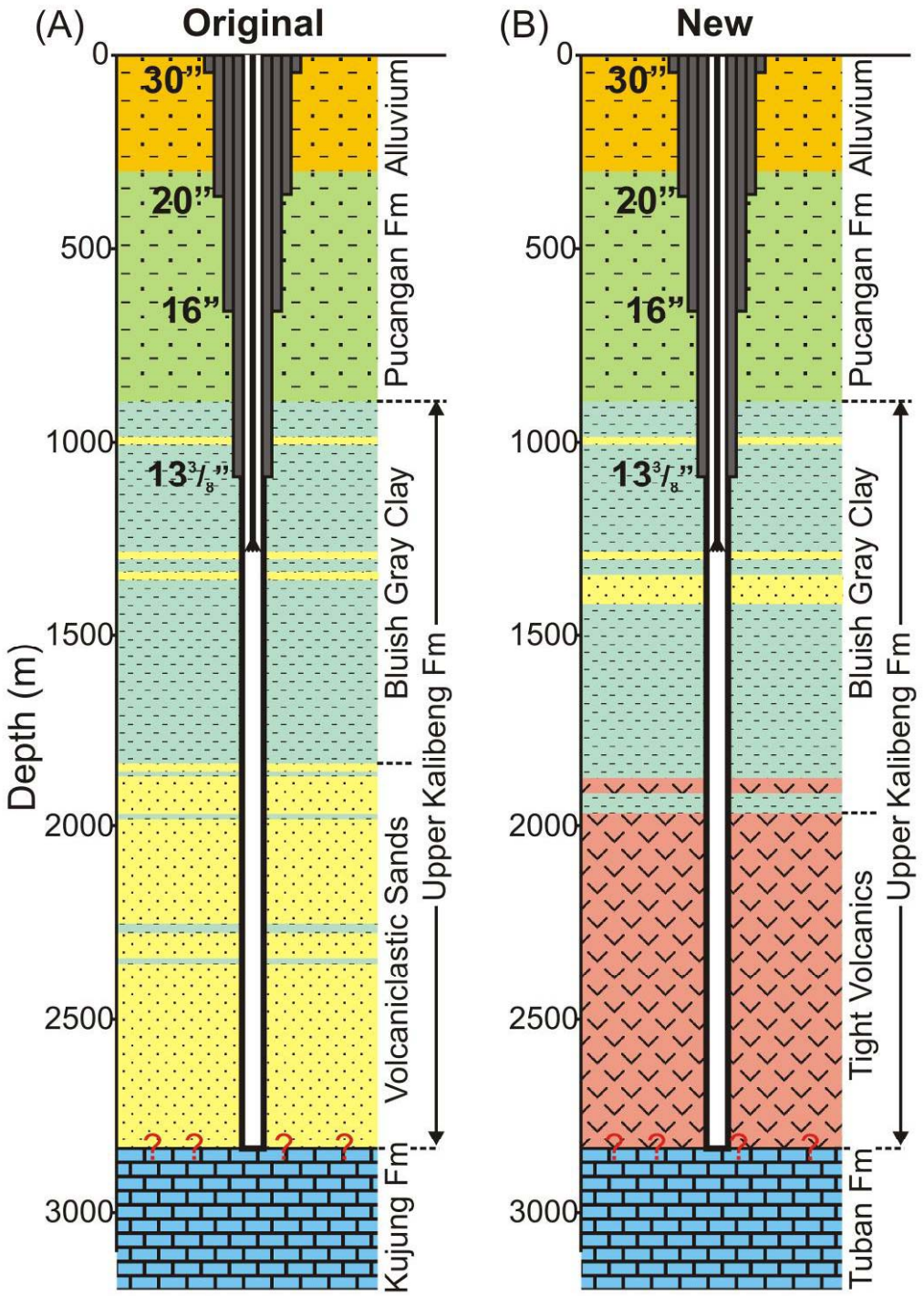
Photo: M. Tingay May 2007

New Interpretation of Lithologies Under Lusi

1) Volcaniclastic sands reinterpreted as tight volcanics.

2) Deep carbonates reinterpreted as Miocene Tuban or Prupuh Fm reefal carbonates.

Stratigraphy modified from Tingay et al., 2008



Why Volcanics and Not Volcaniclastic Sands?

- Close inspection of cuttings reveals error in original mud logger interpretation.

- Cuttings comprised of andesite, dacite, welded tuffs - lava flows, ash and maybe lahars.

- Rocks primarily ground down to sand and gravel sized fragments by bit (very low ROP, high WOB).

- Pleistocene-Recent Penanggungan volcanic complex 15km SW of Lusi.

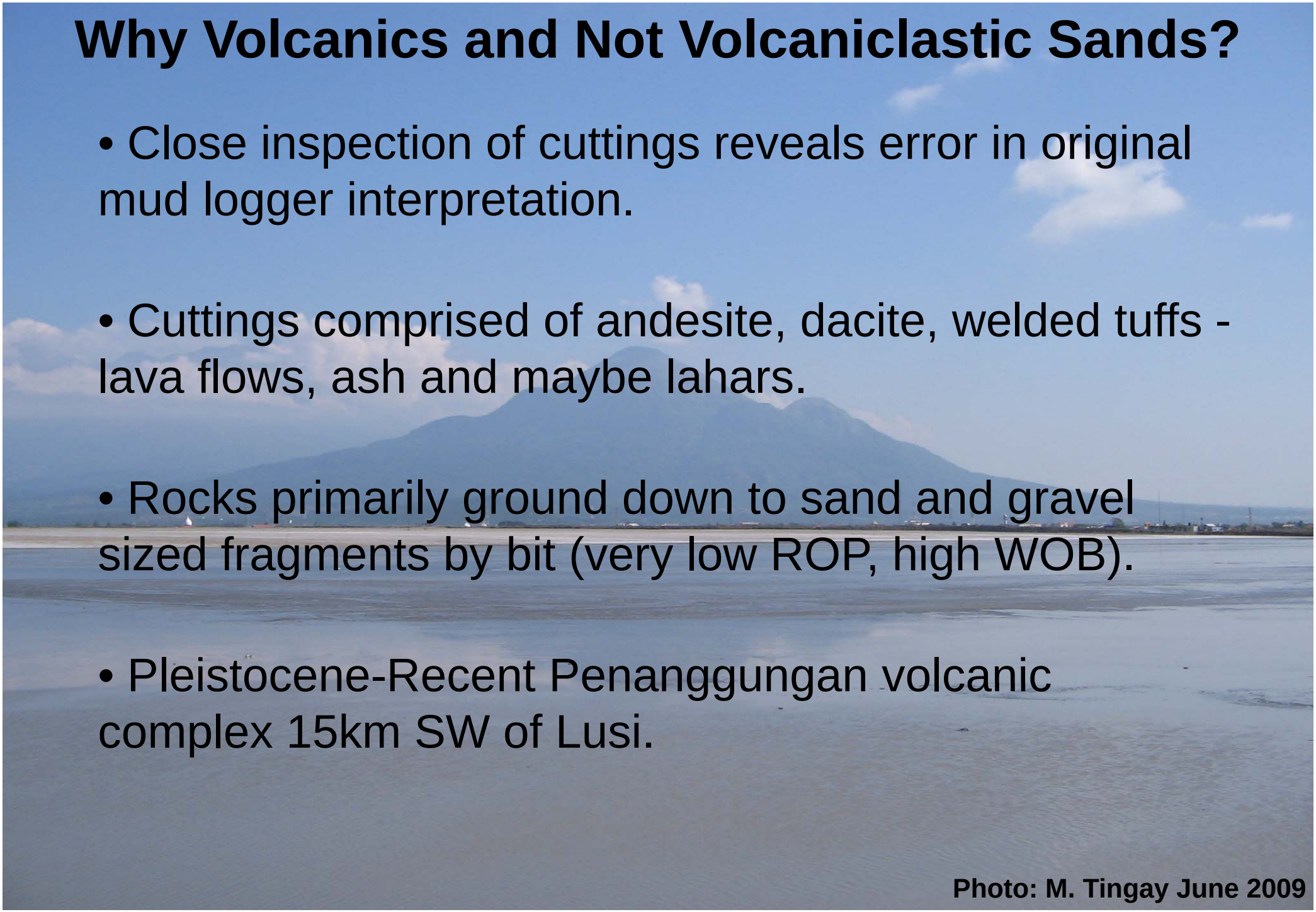


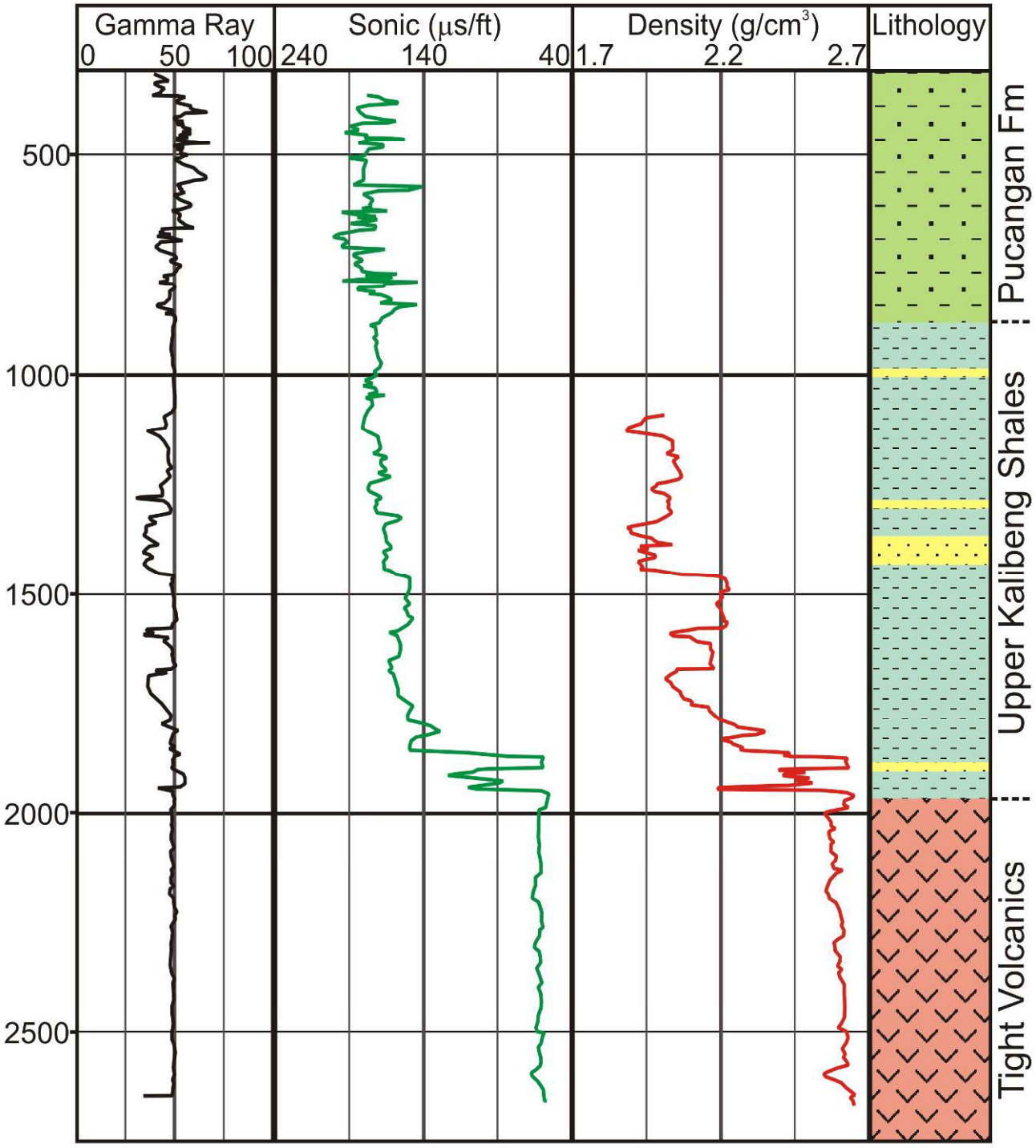
Photo: M. Tingay June 2009

Petrophysical logs suggest volcanics

- Uniform log responses
- High density (~2.6 g/cm^3)
- Fast sonic (~65 μs/ft)
- Indicates porosity <5%

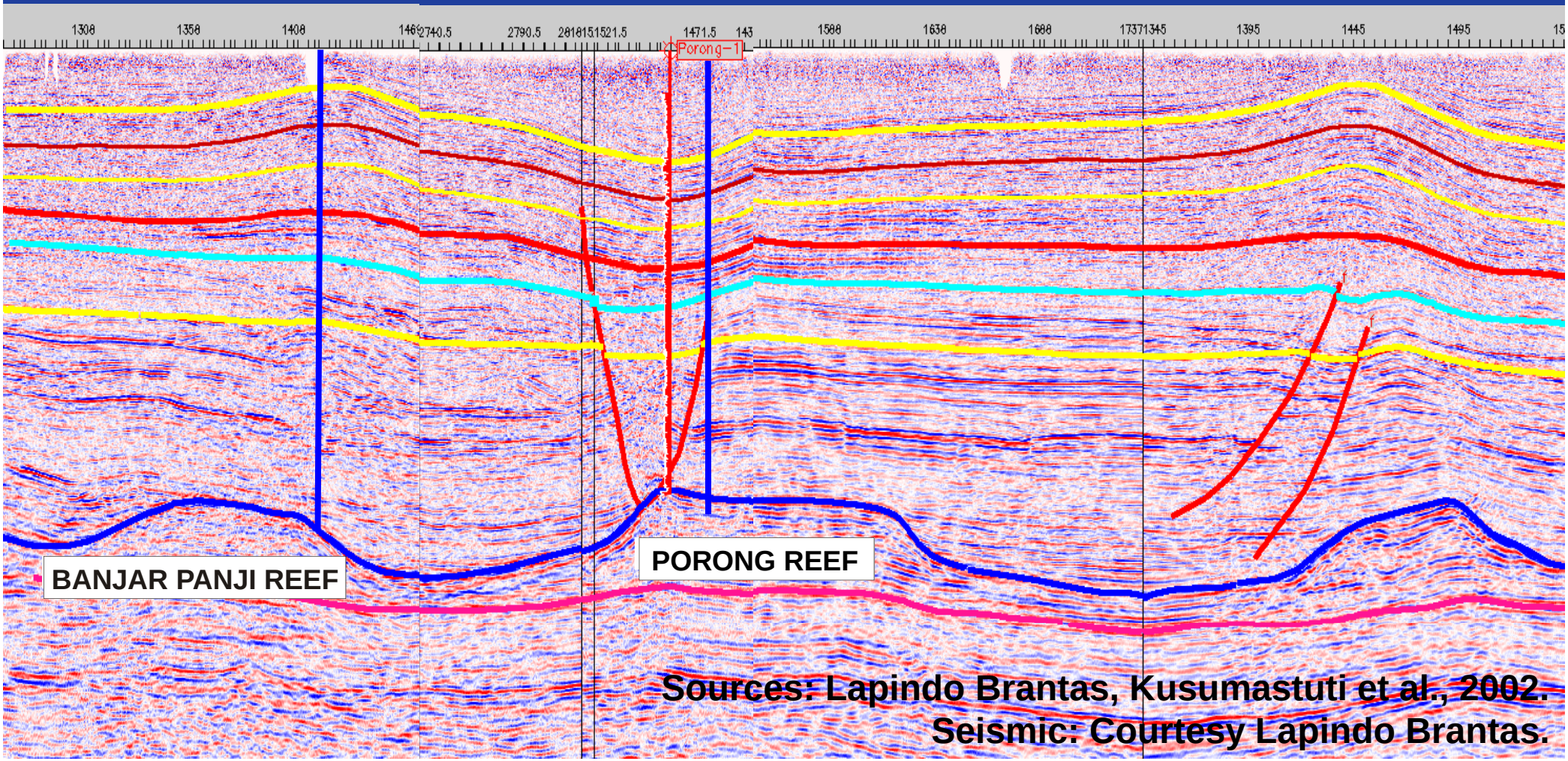
Likely very low matrix permeability (high fracture permeability?).

Source: Schlumberger
BJP-1 Data Montage



WHY NOT THE KUJUNG CARBONATES?

- Oligocene Kujung Fm is primary reservoir unit in East Java Basin.
- Strontium ratios from Porong-1 (7 km away) show carbonates 16 Ma.
- Suggests carbonates Mid Miocene Tuban or Prupuh Formations.



Sources: Lapindo Brantas, Kusumastuti et al., 2002.
Seismic: Courtesy Lapindo Brantas.

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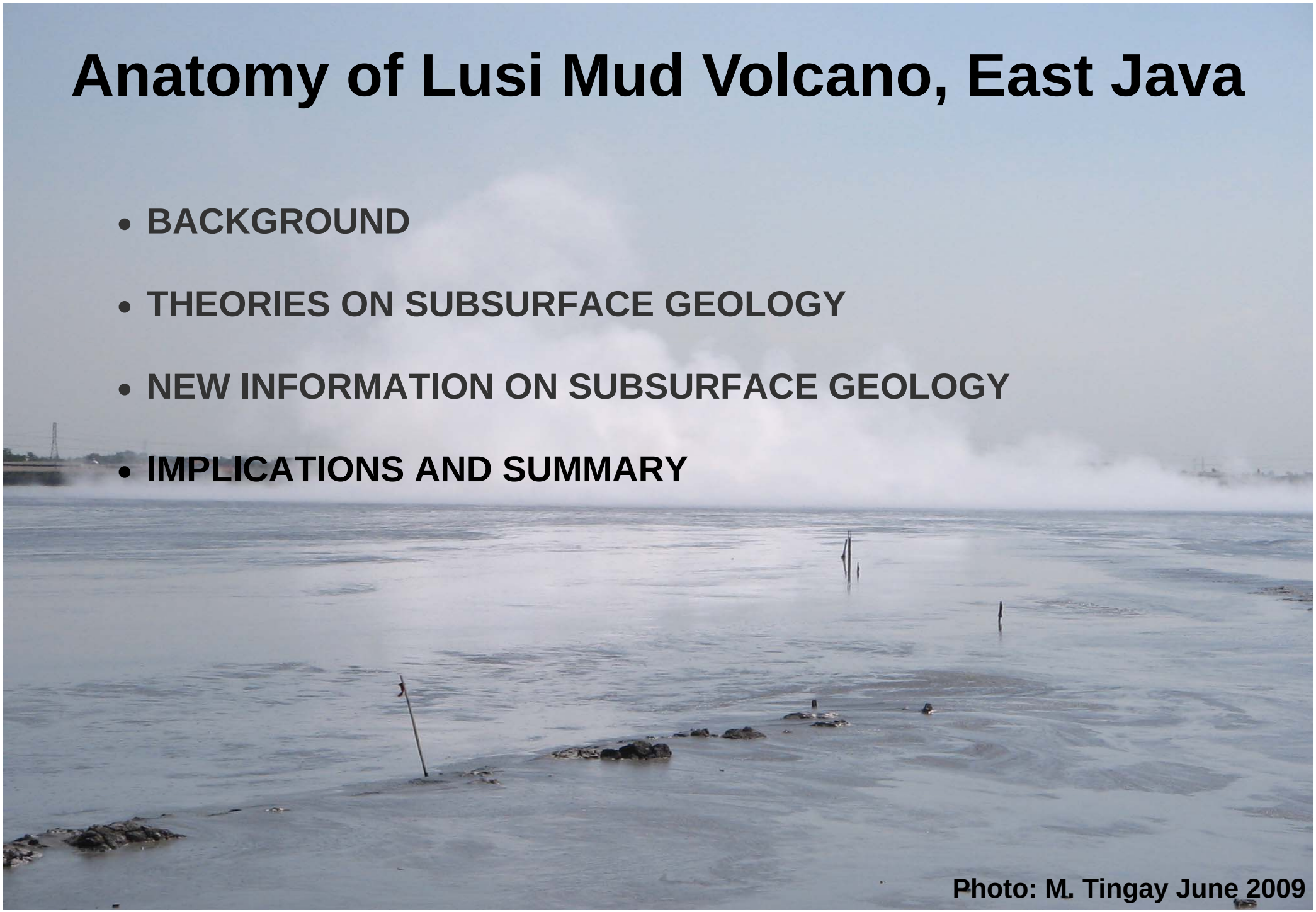
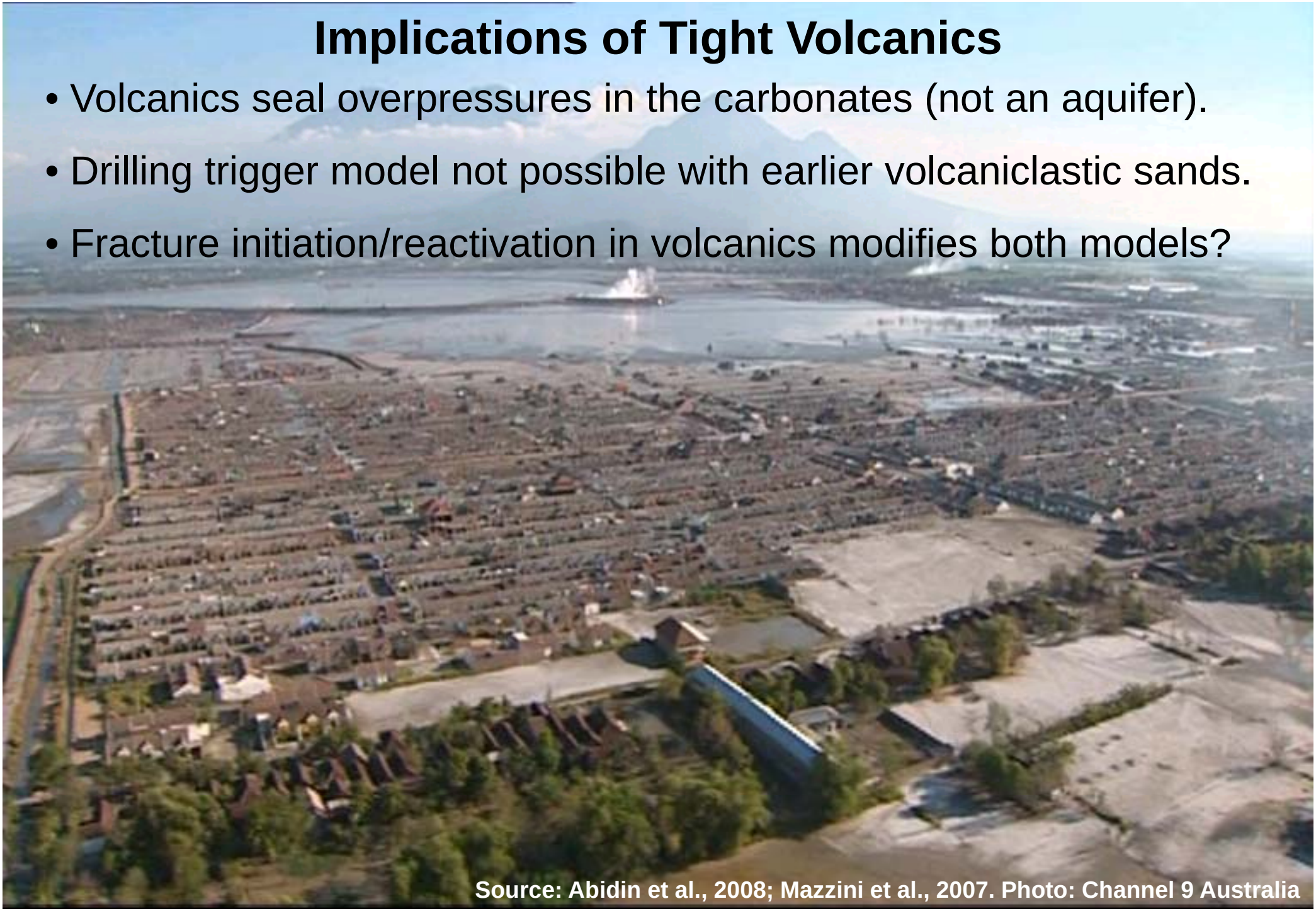


Photo: M. Tingay June 2009

Implications of Tight Volcanics

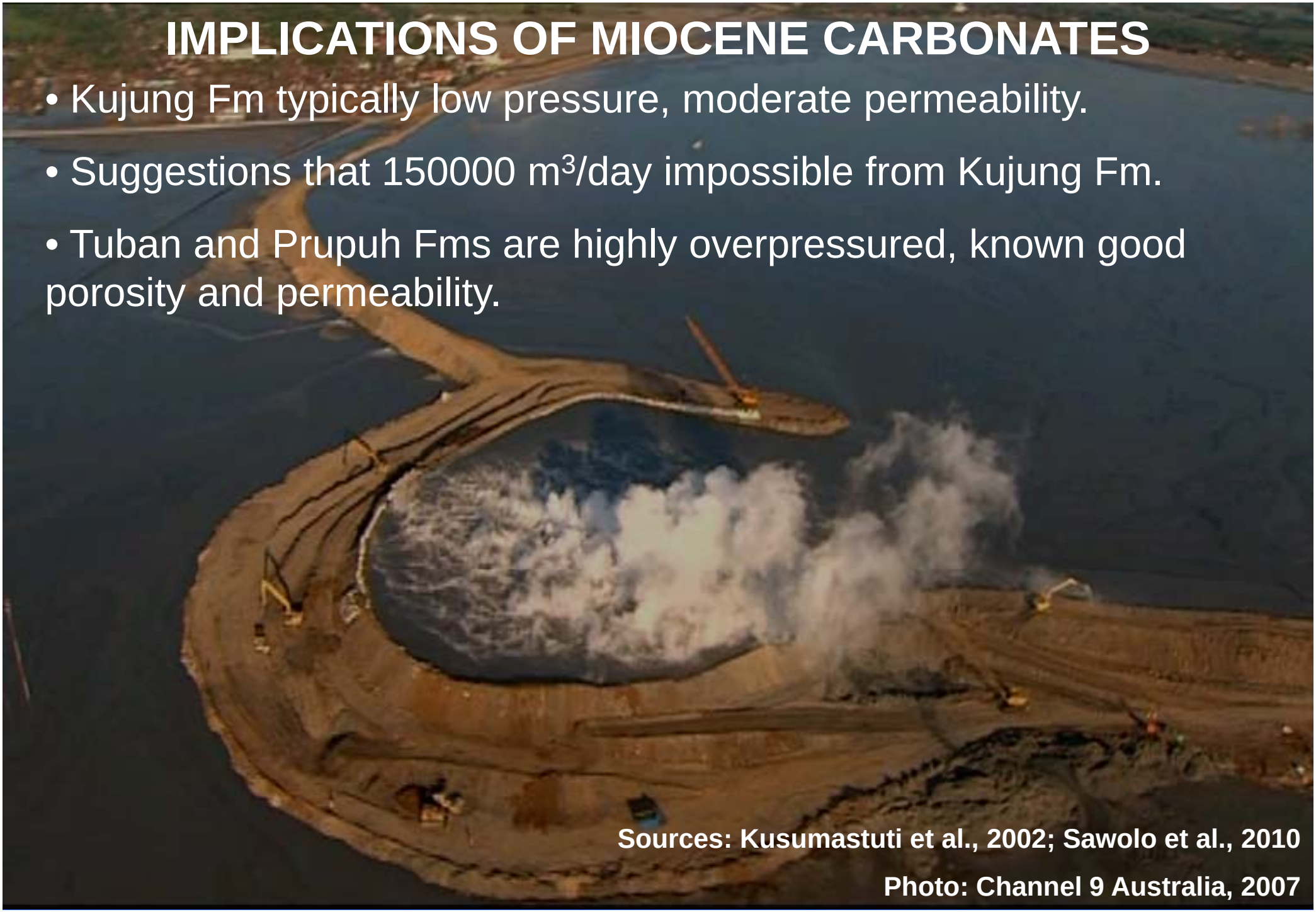
- Volcanics seal overpressures in the carbonates (not an aquifer).
- Drilling trigger model not possible with earlier volcaniclastic sands.
- Fracture initiation/reactivation in volcanics modifies both models?



Source: Abidin et al., 2008; Mazzini et al., 2007. Photo: Channel 9 Australia

IMPLICATIONS OF MIOCENE CARBONATES

- Kujung Fm typically low pressure, moderate permeability.
- Suggestions that 150000 m^3/day impossible from Kujung Fm.
- Tuban and Prupuh Fms are highly overpressured, known good porosity and permeability.



Sources: Kusumastuti et al., 2002; Sawolo et al., 2010

Photo: Channel 9 Australia, 2007

SUMMARY

- Subsurface geology and plumbing system largely unconstrained (H_20??).

- New analysis revises stratigraphy: shales now interpreted to be underlain by tight volcanic sequences and Miocene Tuban or Prupuh Fm carbonates.

- Volcanics offer a seal to overpressures in carbonates.

- Carbonate age suggests unreliable to use Kujung Fm as analogue.

- Both models still have unexplained issues: uncertainty means 40000 people left displaced with minimal aid and only partially compensated.

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

Acknowledgements and Thanks:

Durham, UK: Dick Swarbrick and Richard Davies for discussions on Lusi eruption.

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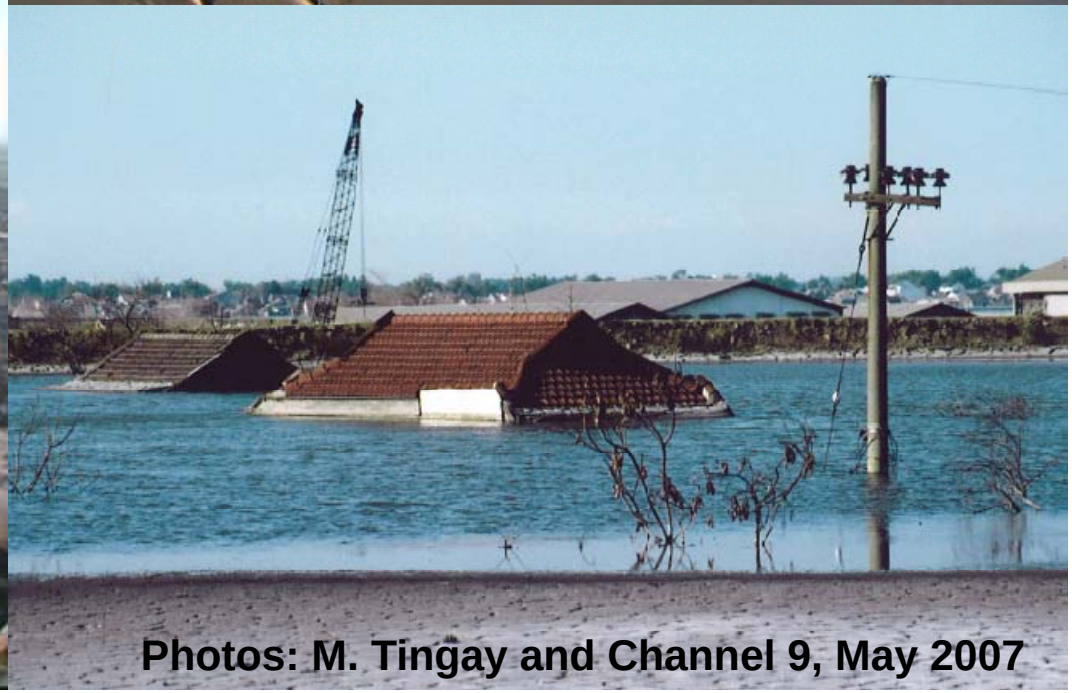
Thanks to Howard Sacre (**60 Minutes, Channel 9 Australia**), Grace Duran (**Greenpeace**) and Rohman Budijanto (**Jawa Pos**) for video and photos of Lusi.

Thank You!!



Photos: M. Tingay and Channel 9, May 2007