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Lusi mud eruption triggered by geometric focusing of seismic waves

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The Lusi mud eruption in Java, Indonesia, began in May 2006 and is ongoing. Two different triggers have been proposed. The eruption could have been triggered by drilling at a gas-exploration well, as evidenced by pressure variations typical of an internal blowout1, 2. Alternatively, fault slip associated with the M6.3 Yogyakarta earthquake two days before the eruption could have mobilized the mud3, as suggested by mixing of shallow and deeply derived fluids in the exhaling mud3, 4 and mud-vent alignment along a tectonic fault. Here we use numerical wave propagation experiments to show that a high-impedance and parabolic-shaped, high-velocity layer in the rock surrounding the site of the Lusi eruption could have reflected, amplified and focussed incoming seismic energy from the Yogyakarta earthquake. Our simulations show that energy concentrations in the mud layer would have been sufficient to liquefy the mud source, allowing fluidized mud and exsolved CO2 to be injected into and reactivate the Watukosek Fault. This fault connects hydraulically to a deep hydrothermal system that continues to feed the eruption. We conclude that the Lusi mud eruption was a natural occurrence. We also suggest that parabolic lithologies with varying acoustic impedance can focus and amplify incoming seismic energy and trigger a response in volcanic and hydrothermal systems that would have otherwise been unperturbed.

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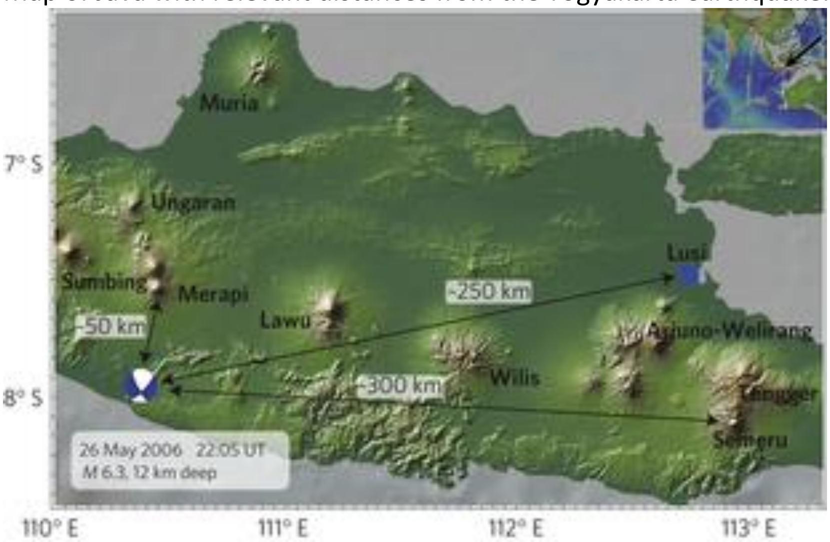
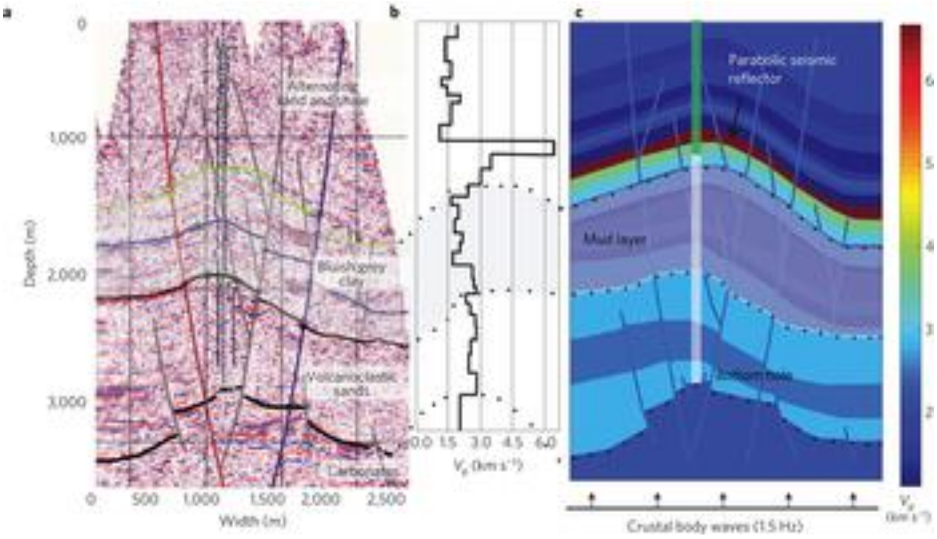
At a glance

Figure 1: Map of Java with relevant distances from the Yogyakarta earthquake. close
Map of Java with relevant distances from the Yogyakarta earthquake.



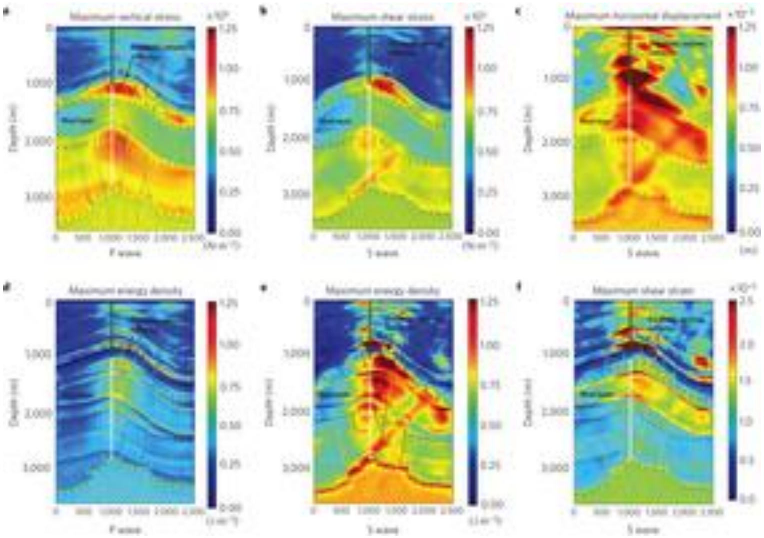
The blue square marks the position of Lusi and arrows show the distance between the epicentre of the Yogyakarta earthquake and the systems that responded to that event.

Figure 2: Geometry, Vp variations with depth and model of Lusi used in the numerical study. close
Geometry, Vp variations with depth and model of Lusi used in the numerical study.



a, Seismic profile of the geological structures8 beneath Lusi used to reconstruct the geology of the model. b, Vertical profile for V p velocities used in the model10. The acoustic impedance of faults is not known, so we assumed ρ = 2,…

Figure 3: Results of the numerical study. close
Results of the numerical study.



Simulation results for: a,d, P wave; and b,c,e, f, S wave at 1.5 Hz. e, Peak energy density of 1.25 J m−3 is reached above the seismic reflector and in the mud layer, demonstrating how the domed structure geometrically focuses energy.…

Figure 4: Conceptual stress path and proposed scenario for triggering the Lusi mud eruption. close
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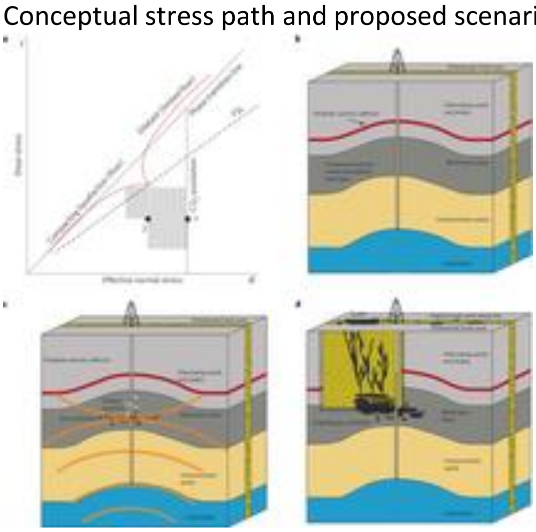

a, Amplified seismic energy perturbs the initial stress state (1), increasing pore pressure through cyclic shear stressing. Aftershocks (2) cyclically load the (impedance-reduced) mud layer, reaching the FSL. At the FSL, the mud layer…

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Contributions

M.L. conducted the study, collected the data and constructed the geological model; E.H.S. conducted the numerical studies; F.F. conducted the seismological analysis; S.A.M. designed and coordinated the study and jointly wrote the manuscript with M.L. All authors contributed equally to the content.

Competing financial interests

The authors declare no competing financial interests.

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