Precursors to eruptions at large calderas: Rabaul Caldera, Papua New Guinea

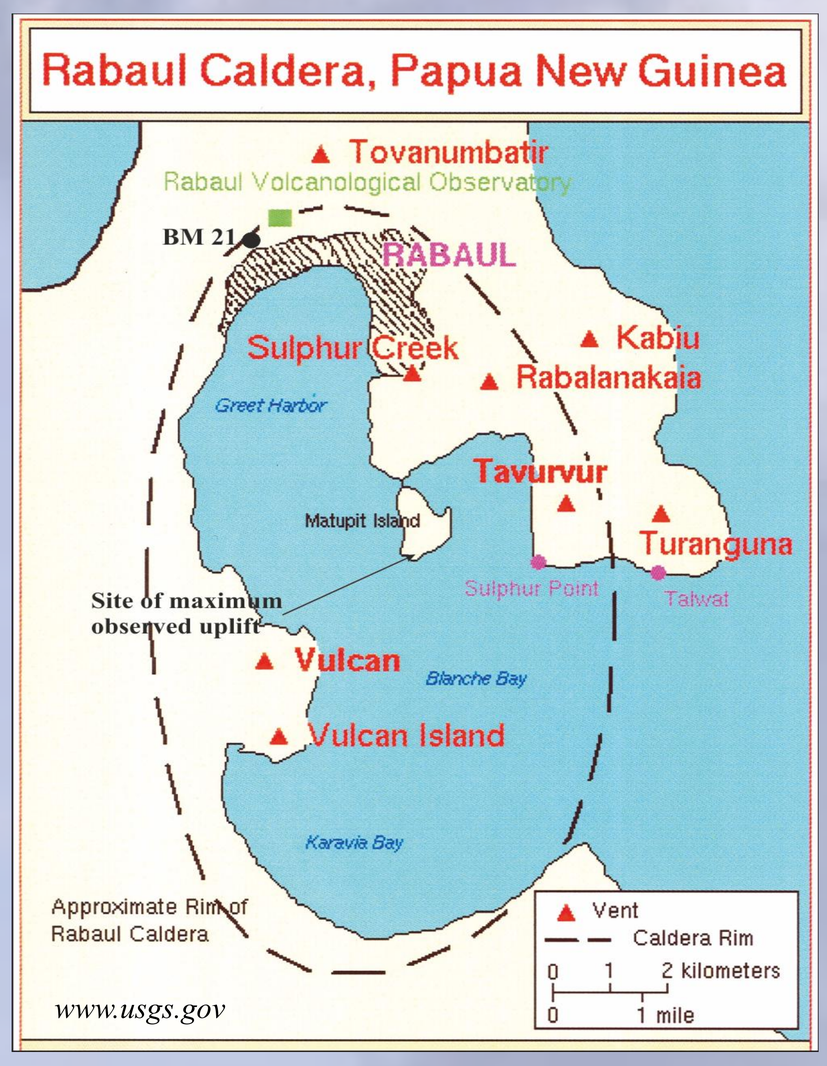
Robert M. Robertson and Christopher R.J. Kilburn

Aon Benfield UCL Hazard Centre, Department of Earth Sciences,
University College London, Gower Street, London WC1 6BT, U.K. (r.robertson@ucl.ac.uk)

1 Introduction

Each year some 15-20 large calderas show signs of unrest through ground uplift or elevated seismicity. Most episodes do not end in eruption. A key goal is distinguish between false alarms and true pre-eruptive phenomena.

Here we re-analyse the behaviour of Rabaul caldera in Papua New Guinea, which, in the past 40 years has provided excellent examples of accelerated unrest without eruption, as well as eruption without accelerated unrest until a matter of hours beforehand.



2. Caldera unrest at Rabaul

Uplift

Extensive monitoring of Rabaul Caldera began in 1973, after an increase in local seismicity and ground deformation (Figs 1 & 2). Uplift at c. 10 cm/year was recorded at Matupit Island, near the centre of the caldera *(right*). This increased to about 40 cm/year between September 1983 and August 1985, before declining without eruption to 2-3 cm a year. A second phase of rapid uplift (at 40 cm/year) began in late 1993, culminating on 19 September 1994 with nearly simultaneous eruptions at Tavurvur and Vulcan, on opposite sides of the caldera. The eruptions marked the end of almost 51 years of repose.

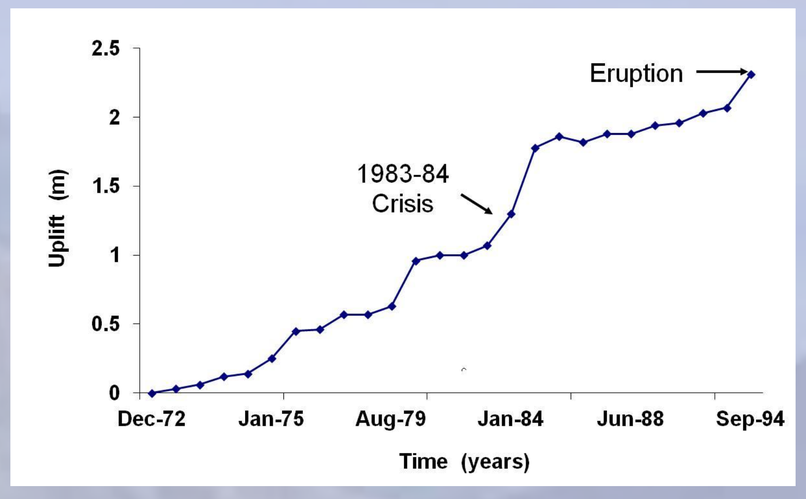


Figure 1. Uplift measured near Matupit Island relative to benchmark BM21 in the north (Finlayson, pers. comm.).

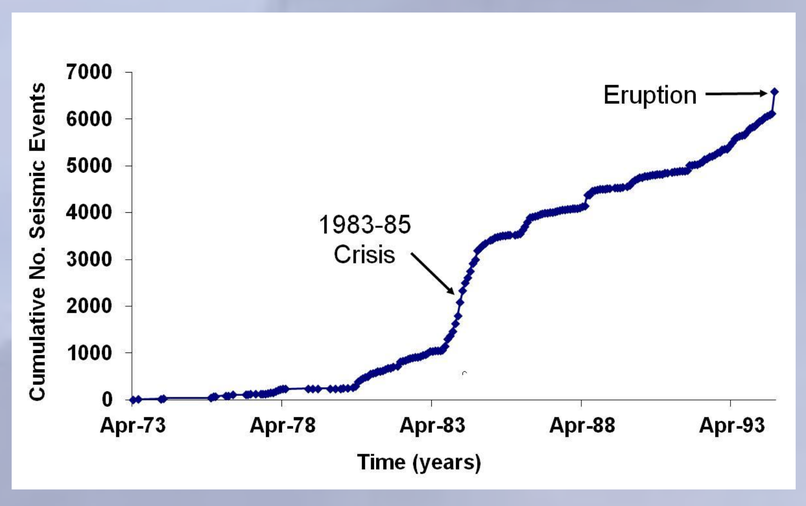
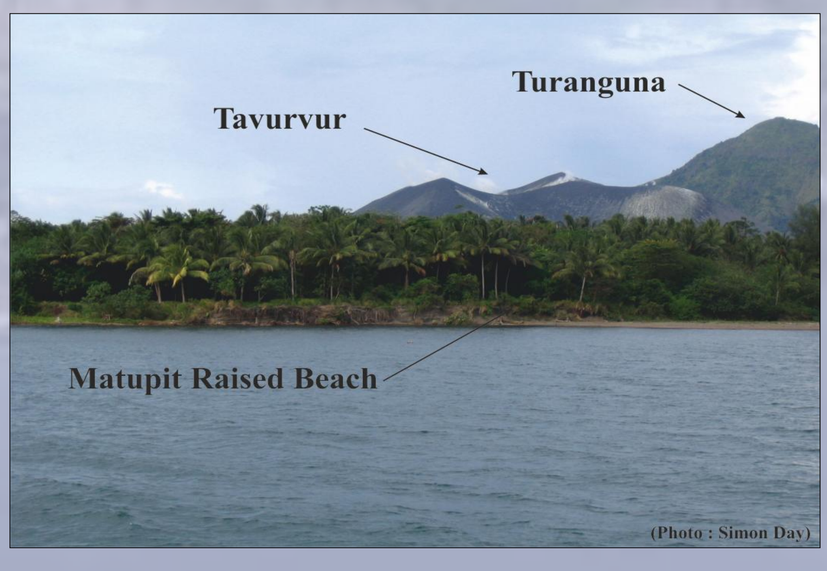


Figure 2. Cumulative number of seismic events, 1973-1994. (Blong and McKee, 1994)

Seismicity

Uplift was accompanied by local seismicity, or volcano-tectonic (VT) events, with event magnitudes typically less than 3. Between 1973 and 1985, the mean seismic event rate appears to change in proportion to the rate of uplift. However, following the 1983-85 crisis, the event rate maintained its pre-1983 values, whereas the rate of uplift had slowed to about one-tenth of its pre-1983 value. From 1993, the mean event rate increased with an increase in uplift rate, resembling conditions before 1983. On 18 September 1994, a Magnitude 5.1 earthquake occurred beneath Rabaul's harbour, followed by 27 hours of seismic swarms before eruptions began at Tavurvur and Vulcan (Fig. 2).



Looking east across Matupit with Tavurvur in the background. The raised beach was formed before the 1970s.

3. Combined strain and seismicity

The time series for uplift and seismicity appear to yield conflicting trends before the non-eruptive crisis in 1983-1985 and the approach to eruption in 1994. In particular, the rapid onset of the eruption appears unusual if it assumed that the crust had previously been under the same condition of strain as before the 1983-1985 crisis.

More coherent patterns emerge when comparing cumulative seismicity with uplift (Fig. 3). During 1973-1993, the cumulative number of VT events increased exponentially with uplift, whereas between 1993 and the 1994 eruption, the relation was more closely linear. This behaviour is consistent with fracturing occurring under a change from an increasing to a constant stress (Kilburn, 2012). Thus Fig. 3 can be viewed as a proxy for a conventional stress-strain diagram, in which stress and strain increase before reaching a creep phase (constant stress, increasing strain) that precedes bulk failure.

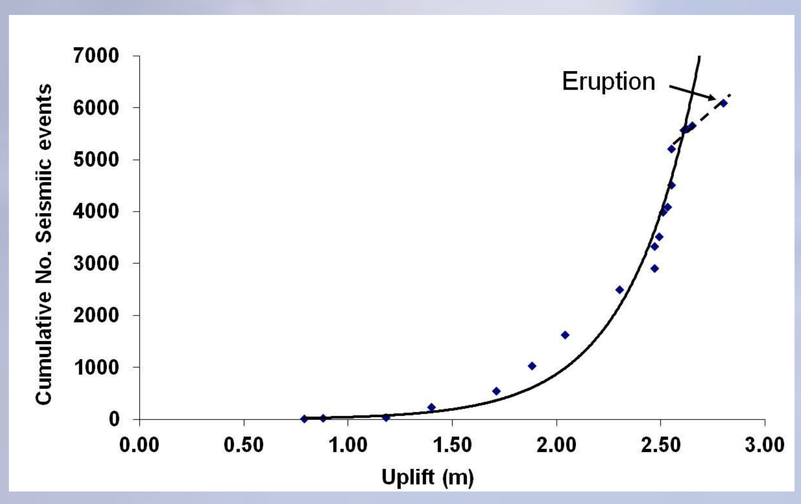


Figure 3. Exponential and quasi-linear trends between cumulative seismicity and uplift, 1973-1993.

Throughout 1973-1993, therefore, strain was progressively increasing in the crust. The potential for bulk failure and eruption occurred when the total strain had reached a critical value, *independent* of the variable rate at which that strain had increased (Fig. 1). Thus rapid rates of change with time in a precursor need not indicate that an eruption is imminent *unless the total strain has also reached a critical value*.

When close to the critical strain, only a modest perturbation may be sufficient to drive an eruption. The 1994 Magnitude 5.1 earthquake may have provided the necessary perturbation.

4. Conclusions

- Strain and fracturing accumulate in the crust during long-term uplift at large calderas.
- The potential for eruption increases with the accumulated strain.
- Accelerating rates of strain and fracturing with time need not indicate that an eruption is imminent, unless the accumulated strain has also reached a critical value.

References. Blong R.,and McKee C.O. (1994) The Rabaul eruption 1994; Finlayson D. M. (Personal Communication, 2006); Kilburn, C.R.J. (2012) J Geophys Res, doi: 10.1029/2011JB008703; McKee CO, Lowenstein PL, De Saint Ours P, Itikarai I, Mori JJ (1984). Bull. Volcanol. 47: 397-411; Saunders SJ (2001). Bull. Volcanol. 63: 406-420

Aon Benfield UCL Hazard Centre

VOLCALERT

***Background Photo of Tavurvur*: W.J.McGuire.**