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Using Bayesian Belief Networks and event trees for volcanic hazard assessment and decision support : reconstruction of past eruptions of La Soufrière volcano, Guadeloupe and retrospective analysis of 1975-77 unrest.

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Since 1992, mild but persistent seismic and fumarolic unrest at La Soufrière de Guadeloupe volcano has prompted renewed concern about hazards and risks, crisis response planning, and has rejuvenated interest in geological studies. Scientists monitoring active volcanoes frequently have to provide science-based decision support to civil authorities during such periods of unrest. In these circumstances, the Bayesian Belief Network (BBN) offers a formalized evidence analysis tool for making inferences about the state of the volcano from different strands of data, allowing associated uncertainties to be treated in a rational and auditable manner, to the extent warranted by the strength of the evidence. To illustrate the principles of the BBN approach, a retrospective analysis is undertaken of the 1975-77 crisis, providing an inferential assessment of the evolving state of the magmatic system and the probability of subsequent eruption. Conditional dependencies and parameters in the BBN are characterized quantitatively by structured expert elicitation. Revisiting data available in 1976 suggests the probability of magmatic intrusion would have been evaluated high at the time, according with subsequent thinking about the volcanological nature of the episode. The corresponding probability of a magmatic eruption therefore would have been elevated in July and August 1976; however, collective uncertainty about the future course of the crisis was great at the time, even if some individual opinions were certain. From this BBN analysis, while the more likely appraised outcome - based on observational trends at 31 August 1976 - might have been 'no eruption' (mean probability 0.5; 5-95 percentile range 0.8), an imminent magmatic eruption (or blast) could have had a probability of about 0.4, almost as substantial. Thus, there was no real scientific basis to assert one scenario was more likely than the other. This retrospective evaluation adds objective probabilistic expression to the contemporary volcanological narrative, and demonstrates that a formal evidential case could have been made to support the authorities' concerns and decision to evacuate. Revisiting the circumstances of the 1976 crisis highlights many contemporary challenges of decision-making under conditions of volcanological uncertainty. We suggest the BBN concept is a suitable framework for marshalling multiple observations, model results and interpretations – and all associated uncertainties - in a methodical manner. Base-rate eruption probabilities for Guadeloupe can be updated now with a new chronology of activity suggesting that 10 major explosive phases and 9 dome-forming phases occurred in the last 9150 years, associated with $\geq$ 8 flank-collapses and $\geq$ 6-7 high-energy pyroclastic density currents (blasts). Eruptive recurrence, magnitude and intensity place quantitative constraints on La Soufrière's event tree to elaborate credible scenarios. The current unrest offers an opportunity to update the BBN model and explore the uncertainty on inferences about the system's internal state. This probabilistic formalism would provoke key questions relating to unrest evolution: 1) is the unrest hydrothermal or magmatic? 2) what controls dyke/intrusion arrest and hence failed-magmatic eruptions like 1976? 3) what conditions could lead to significant pressurization with potential for explosive activity and edifice instability, and what monitoring signs might be manifest?