Real-time forecasting of catastrophic rock failure and implications for predictability of volcanic eruptions

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There are a variety of methods for forecasting the probability of a volcanic eruption in a given time period, often relying as much on expert judgement as formal analysis of geophysical, geodetic and geochemical data. Physical theories are commonly based on laboratory constitutive rules for catastrophic rock failure due to sub-critical crack growth under a constant load or loading rate. In both cases an accelerating rate of deformation or acoustic emissions is predicted with a well-defined inverse power law form that is consistent with independent laboratory observation. Similar precursors have also been seen to first order in seismicity data before volcanic eruptions in individual and stacked sequences, as well as prior to some intrusion events. To date most of these analyses are retrospective, so the failure time and outcome is already known. Success in such hind-casts is a necessary but not sufficient criterion for assessing the true forecasting power or quality in real time, and is a prime motivation for the development of the global Collaboratory for the Study of Earthquake Predictability (CSEP), where forecasts are lodged verifiably in advance. Here we assess the potential significance and utility of real-time forecasting using such constitutive rules by applying a variety of techniques. First we describe the results of Monte-Carlo simulation of realistic ideal model sequences with an appropriate degree of noise added. The best results are obtained when maximum likelihood statistical models that take appropriate account of the error structure are used. This method has yet to be commonly applied in volcanic seismology. Even so there is large uncertainty quite close to the catastrophic failure time, so reliable forecasting may not be possible even in this ideal case. Communication of this uncertainty, and deciding in advance on appropriate actions to be taken with low-probability forecasts, then become as indispensable as making the forecast itself. The next step is to quantify forecast quality in a controlled laboratory setting by modern real-time data assimilation techniques. We describe a prototype infrastructure for this exercise that streams live data from a participating laboratory via a user-friendly portal, analyses the data and makes continuously-updated forecasts in real time including uncertainty, and will present some preliminary results if available. Finally we apply the method to data from recent volcanic eruptions, analysing the results as if they had come in real time. In this case the uncertainties are not purely statistical, they are also epistemic, and continuous multiple-hypothesis testing along the CSEP model is likely to be needed in cases which do not follow the simple laboratory pattern. In this case model discrimination using standard methods such as Information Criteria or Bayes ratio may also not be possible in real time until very near the eruption.