# Quantifying the intensity of unrest: introducing the Volcanic Unrest Index (VUI)

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The observation and interpretation of volcanic unrest is a key element of eruption forecasting. Unrest is caused by the interaction of magma with surrounding rocks and fluids. This can result in detectable signals such as seismicity, ground deformation and/or hydrothermal/geochemical changes. The integration and interpretation of the multiple parameters is important for eruption forecasting and would enable the comparison of episodes, but is difficult due to the inherent complexity of the system, multiple monitoring techniques and a variety of data formats. No transferrable thresholds exist to divide the wide range of multivariate activity into "background" activity and "unrest", the terms commonly used in literature and Volcanic Alert Level (VAL) descriptions. To encapsulate the complete range of activity at a volcano during periods of quiescence (including background activity to heightened unrest), the description Non-Eruptive Volcanic Activity (NEVA) is used.

A tool to quantify the overall intensity of NEVA is presented here, called the Volcanic Unrest Index (VUI). Observations ranging from qualitative historical descriptions from past episodes to quantitative real-time monitoring data can be applied to a framework. Thresholds on the framework are tailored to each volcano individually, providing a definition of "unrest". A simple calculation results in an index summarising the intensity of activity. The creation of the VUI involved a wide literature search to ascertain the current state of knowledge of magmatic systems and processes. Multiple iterations with volcanologists from a range of volcanic settings, institutions and countries resulted in the tool presented here. The VUI

• rates the intensity of historical unrest activity, enabling comparisons of episodes over time,

• allows the rapid identification of activity reaching "unrest" status, therefore assisting with VAL changes,

• prompts the early collection and analysis of historical observations to ascertain the range of NEVA intensity, which feeds into eruption forecasting models, and

• assists with the communication of multitudinous, complex information simply and rapidly to non-scientists.

A case study is presented for Taupo Caldera (New Zealand), a rhyolitic volcano which most recently erupted in 232 AD. A multi-parameter catalogue of unrest over the past 140 years at Taupo has recently been completed. The VUI has been used to translate the complex information into an easily understood time-series plot, demonstrating the wide range of intensity of past activity at this volcano. This has helped communicate the history of NEVA at Taupo Caldera to non-scientists from a multi-agency planning group for the mitigation of risks involved with caldera unrest (the Caldera Advisory Group). The information transfer enables the end-users to have an increased understanding of the range of past and potential future volcanic unrest episodes at Taupo.