Assessment of long-term volcanic hazard using a Cox process with assimilation of tectonic data and geophysics

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Introduction

Quantification of long-term volcanic hazard becomes of paramount importance when assessing risks related to the isolation of potential geological repository sites. Such risk evaluation concerns many industrial regions around the world, in particular the Japanese islands due to their tectonically active nature.

For sites near volcanically active regions, long-term volcanic hazard constitute the dominant source of uncertainty as input for risk assessments. Uncertainty is mainly related to imperfect knowledge of non-linear volcanic processes, to space-time variability of distribution and intensity for volcanic events, and to a limited amount of information. For these reasons, the estimation of volcanic hazard based on a probabilistic formalism is internationally getting more frequently employed [1]. In addition, recent events at Fukushima highlight the importance of using probabilistic approaches to assess tectonic hazards and risks to critical facilities in potentially susceptible locations [2]. Therefore, it is of prime importance for both the Nuclear Waste Management Organisation of Japan (NUMO) and the wider geoscientific community to have a probabilistic methodology for the assessment of long-term volcanic hazard. In Japan, the siting of a geological high-level radioactive waste (HLW) repository will consider regions that are not obviously excluded on the basis of recent and current volcanism. At the beginning of its repository siting program in 2002, NUMO has initiated a long-running project for the development of reliable methodologies for volcanic and tectonic hazard assessment.

The probabilistic methodology for volcanic and tectonic hazard assessment, developed by NUMO [3] with an international team of geoscientists, addresses time frames up to 100'000 years. As part of this methodology, several stochastic

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models were developed using specific geological conceptualisations based on various data sets and information related to past and current volcanic activity, their geophysical signature and related tectonics.

The Cox process constitutes one of the stochastic models that were applied for the estimation of volcanic hazard in Japan [4], [5]. Besides describing the distribution of volcanic events, the Cox process enables the uncertainty characterisation related to its intensity function, considered as random. This stochastic process becomes doubly stochastic and corresponds to a generalisation of the non-homogeneous Poisson process.

The concepts of this model are given below; developments were undertaken in order to extend the assimilation capabilities of the Cox process with respect to additional data types. An illustration is provided using data from Kyushu. We emphasize that this case study is only used as an example; no region in Japan is yet considered specifically as a HLW candidate site.

Concepts

Long-term volcanic hazard assessment requires the characterization of distribution and occurrence of volcanic events. In order to integrate geological and tectonic information, we apply the notion of potential of volcanism which represents the propensity of a given region to be affected by volcanic events. The potential of volcanism, being unknown, is considered as randomly structured within the context of the stochastic model. While the structured part represents the current geological and tectonic knowledge, the random part incorporates the uncertainty, related to processes and parametrisation that is associated with this information.

From a conceptual point of view, based on the current geoscientific knowledge, the following pieces of evidence and hypotheses have to be incorporated within our modeling perspective: (a) the distribution of volcanic events presents spatial patterns describable using a random potential of volcanism, (b) the spatial distribution of volcanic events is expected to be statistically correlated to the geophysical signature of crustal and mantle structures; as well as to the location of active faults, and (c) future events are likely to be located in zones of past activity and their location presents some degree of statistical correlation with geophysics and tectonic data.

For the estimation of volcanic hazard, the developed Cox process is characterized by a multivariate potential of volcanism, due to the assimilation of various data sets, related to geophysics and tectonics.

Illustration

Kyushu is the southernmost and third largest island in the Japanese archipelago. Since the Mesozoic, westward subduction-related processes along the eastern margin of Asia have produced most of the geology of Japan [6]. The subduction of the Philippine Sea Plate beneath the Eurasian Plate at the Ryukyu trench and the Nankai trough (Figure 1) drives the volcanism in the north western, central and southern volcanic regions of the island of Kyushu [7]. Comparison of volcanoes and active faults location displays evidence of some degree of correlation. Other evidence for zones of preferential magma generation beneath Kyushu volcanic arc includes low-velocity anomalies obtained by seismic tomography [8] as well as low-gravity anomalies. Both of these anomalies are likely to correlate with volcano location.

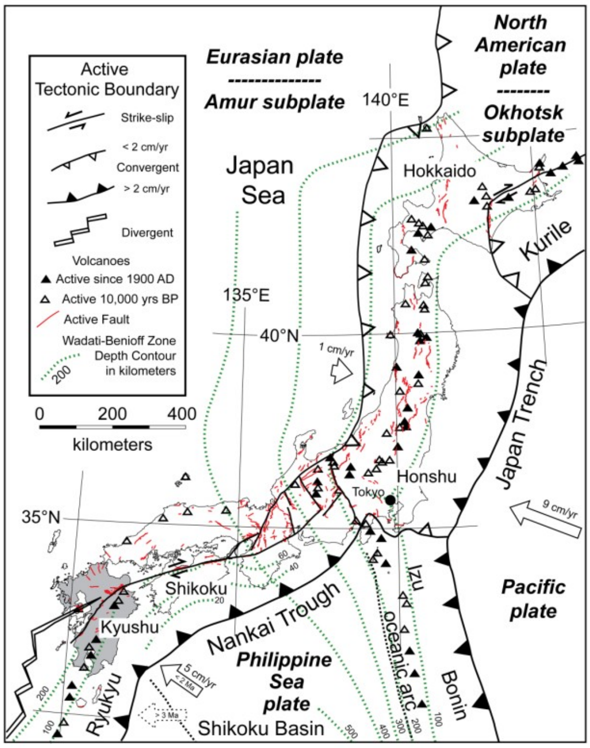

Figure 1 Tectonic context for the island of Kyushu within the Japanese archipelago, after [9].

The aim is the estimation of the probability for the formation of new volcanoes at the scale of Kyushu over a proposed performance period of 100’000 years. All Quaternary types of volcanoes (those active within the last 2 million years) of

Kyushu are considered as representing potentially active volcanic areas for the future.

The Kyushu volcano dataset [9], comprising 240 Quaternary volcanic events, has been created by collecting data from the following different sources: the AIST online Quaternary volcano database [10], various field trips, individual papers and Japanese websites. The age of volcano formation is estimated by taking the oldest available eruption data. The general location for the 76 active faults was obtained from the database of the National Institute of Advanced Industrial Science and Technology [11]. For the gravity data, the regional digital gravity map of Kyushu, established by the Geological Survey of Japan [12] was applied for hazard modelling. These three datasets are displayed in Figure 2.

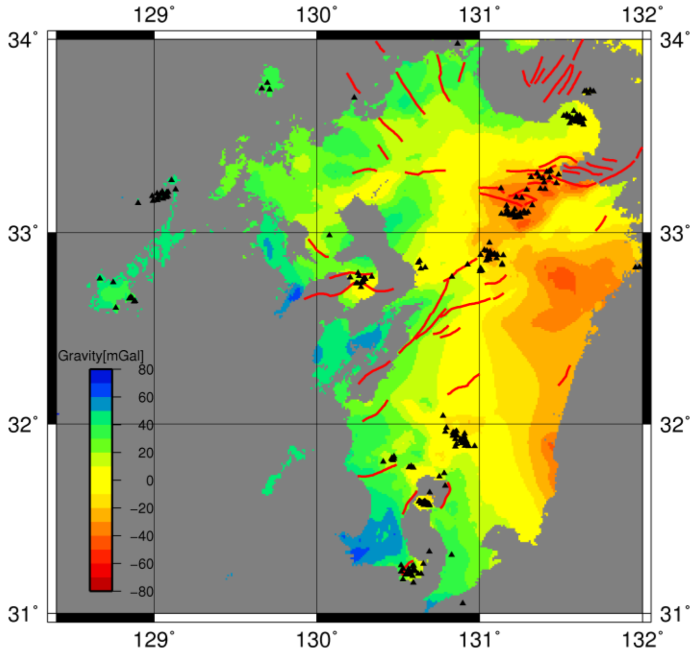

Figure 2 Datasets for Kyushu with Quaternary volcanic events (black triangle), active faults (red line) and Bouguer gravity map (colours).

For the estimation of volcanic hazard for Kyushu with a 5 km x 5 km resolution, the potential of volcanism assimilates the following spatial distributions: (a) Quaternary volcanic events, (b) gravity data and (c) cumulative lengths of active faults.

Using the Cox model, simulations of future volcanic events were performed over a period of 100’000 years for Kyushu. 10’000 Monte Carlo simulations were carried out to obtain stable probability estimates. These results were displayed in form of a volcanic hazard map for Kyushu (Figure 3). Technical details for parameter estimation and related to the Cox simulation method can be found in [13].

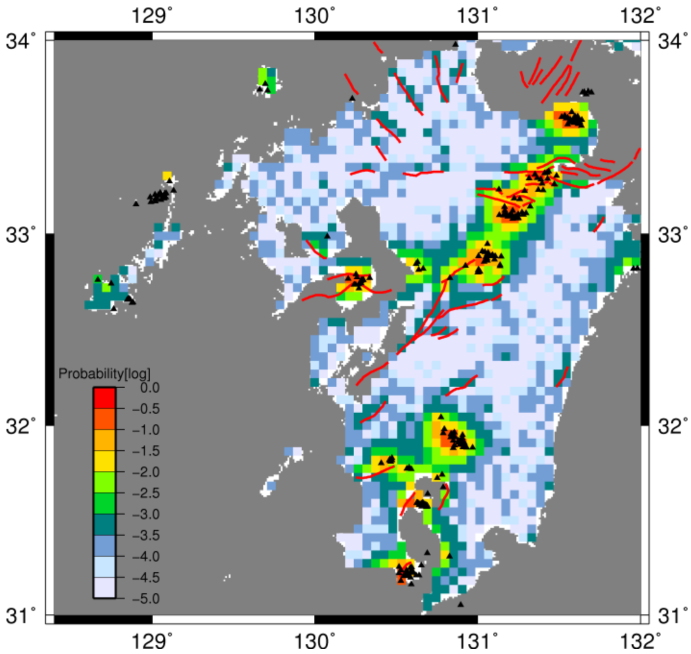

Figure 3 Volcanic hazard map for Kyushu displaying the probability of one or more volcanic event for the next 100'000 years.

Perspectives

By considering a Cox process with a multivariate potential of volcanism, the assimilation of Quaternary geological information, active faults and geophysical data becomes operational for hazard calculations. This modelling approach constitutes a step forwards with respect to the joint analysis and interpretation of tectonic and volcanic data for probabilistic hazard assessments; i.e. it enables improvement of uncertainty characterisation when forecasting volcanic activity on the long term. In particular, the use of multivariate data sets will enhance hazard estimation for non excluded regions away from recent and current volcanic activity.

Additional developments are needed as to include various types of volcanic activity in form of selected scenarios in order to estimate their specific hazards. Finally, stochastic models with non-stationary potential are needed for complex volcanic regions, especially when dealing with time frames beyond 0.1 million years.

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