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Numerical simulation of piezomagnetic changes associated with volcanic activity

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Large changes in the stress field accompanying loading and rupture of crustal rocks during volcanic activity have long been expected to generate associated local magnetic field changes. Stress redistribution induces variations in the magnetization of rocks producing a local piezomagnetic field, which is proportional related to deviatoric stress field. Attempts at modeling changes in piezomagnetic field often involve a great deal of effort due to the complexity of the problem. Over the last decades, straightforward analytical solutions for simplified geometric sources have been devised under the assumption of homogeneous elastic half-space, although geological data and seismic tomography indicate that the medium is elastically heterogeneous. To overcome these intrinsic limitations, we propose the Finite Element Method (FEM), which allows considering topographic effects as well as complicated distribution of medium properties. Firstly, the elastic stress field is solved, then, the distributions of the stress-induced magnetization were estimated from the linear piezomagnetism to calculate the piezomagnetic effect on the ground. Benchmark tests were carried out on the well-known solution of Mogi model to compare the analytical results with numerical ones assuming a homogeneous half-space medium. Once the accuracy of FEM solutions has been verified, we incorporate some realistic features in order to evaluate their effects. Case studies from Etna and Stromboli volcanoes are investigated to assess the performance and the implication of the numerical model. The use of numerical piezomagnetic models provide new insights in the interpretation of volcanomagnetic signals observed during the latest eruptions. Both topography and medium heterogeneity engender perturbations to the piezomagnetic fields produced by a pressurized source under elastic conditions. Such perturbations are more evident in presence of accentuated topography and severe heterogeneity. Hence, neglecting the complexities associated with morphology and rheology in standard analytical studies could yield an inaccurate estimate of model parameters.