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Simulation of magnetotelluric fields at Stromboli volcano using unstructured grid finite element techniques together with digital topography and bathymetry data

Sissy Kütter, Antje Franke-Börner, Ralph-Uwe Börner, and Klaus Spitzer

Institute of Geophysics, TU Bergakademie Freiberg, Freiberg, Germany (klaus.spitzer@geophysik.tu-freiberg.de / +49-3731-392636)

Marine volcanoes are particularly demanding when it comes to applying electric or electromagnetic methods to investigate their interiors. First, the surrounding highly conductive sea water represents a significant difference in conductivity with respect to the volcanic edifice, second, the volcano's topography has great impact on the electromagnetic response, and, third, the surrounding sea bed topography heavily distorts electromagnetic fields in frequency bands that interfere with a certain spatial wavelength and amplitude of the bathymetry. By neglecting these issues severe misinterpretations are the inevitable consequence.

We present different approaches to 3D vector finite element simulation on unstructured grids which are able to compute plain-wave magnetotelluric fields for models including arbitrary surface and sea bed topography. As an example, we consider Stromboli volcano. One major issue is the incorporation of the Stromboli topography using a digital terrain model so that nearly all geometric features affecting the electromagnetic response are considered and an electromagnetic view on Stromboli's interior becomes possible. By carrying out a number of different synthetic experiments it has become obvious that not only the topography of Stromboli island itself is influencing the behavior of the fields but, even stronger, the topography of the surrounding sea bed within a radius of several tens of kilometers. The experiment therefore comprises three steps which gradually approach the complex setting of the target and map the entire volcanic environment with increasing accuracy.

The first step outlines the volcano as a resistive geometric frustum surrounded by conductive sea water and underlain by a resistive substratum. This model already gives fundamental answers concerning the principal frequency-dependent current flow pattern within the edifice and the surrounding sea. For this purpose, the MT response was calculated at the earth/sea and the earth/air interface, respectively, for a period of 1000 s along a profile line of 80 km length centered at the top of the frustum. The most delicate features are encountered at the submarine foot of the volcano and when the profile crosses the shore line. The apparent resistivity slowly decreases while approaching the volcano and steeply increases at its foot. It proceeds in a sigmoidal pattern until the profile reaches the shore line. Then the apparent resistivity drops sharply along the on-shore slope and shows a small spike due to the chopped-off tip of the cone. The whole pattern is symmetric with respect to the center of the frustum giving a valuable cross-check for the accuracy of the simulation. In contrast to the apparent resistivity the phase shows a very stable and smooth behavior with values well below 45 degrees in the vicinity of the volcano. The governing physics is comprehensible if so-called static shift effects are considered. Additional MT frequency soundings were conducted at the top of the frustum and at the sea floor 40 km away from the island giving clear indications for the edifice and the conductive sea in the former case and the vanishing energy of the electromagnetic field due to the strong skin effect within the conductive sea water in the latter case.

The second step incorporates a digital terrain model only of the volcanic edifice surrounded by a flat sea bed and the third step includes the regional sea bed topography in addition resulting in a significantly increased complexity of the magnetotelluric response. Finally, we raise questions related to spatial data sampling, experimental design and resolution analysis helping to gain optimum information on a volcanic target and to realistically assess the potential and the limits of electromagnetic exploration methods.