GLOBAL VOLCANIC AND ENVIRONMENTAL SYSTEMS SIMULATION
Rome, Italy

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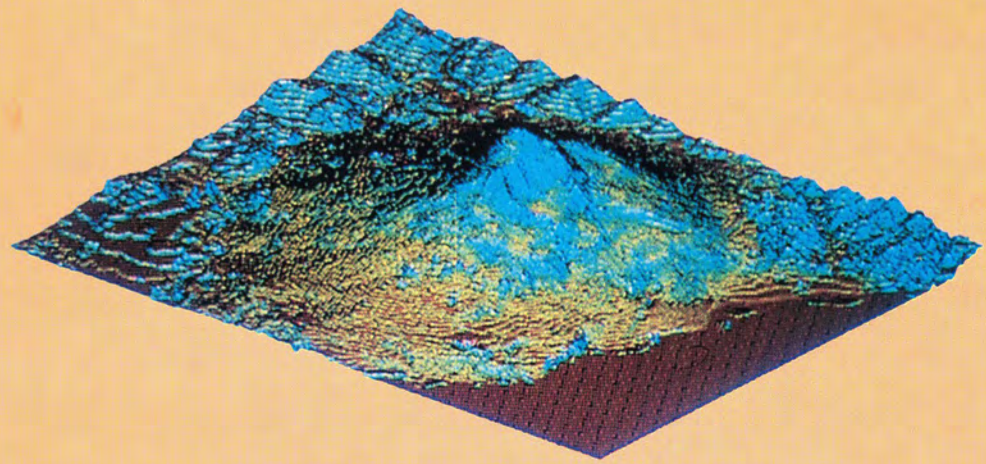

ETNA
Magma and Lava Flow Modeling and Volcanic System Definition Aimed at Hazard Assessment

Commission of the European Communities
Contract: EV5V-CT92-0190
DGXII Climatology and Natural Hazards Unit

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Summary

Magma and Lava Flow Modeling and Fine Structure and Plumbing System Definition Aimed at Volcanic Hazard Assessment at Etna was a research program pertaining to the Etna Laboratory Volcano Project sponsored by the Commission of the European Communities within the Climatology and Natural Hazards Unit of DGXII. The overall objective of the research program was to assess the volcanic hazard at Etna by integrating geological, geophysical, petrological and geochemical data with physical models of magma ascent along conduits and lava flows along the actual topography of the volcano. These data pertain to crack propagation with and without magma-sustained flow, distribution of eruptive cones and fissures, earthquake epicenters, magnetic and electric anomalies, local and global lava flows, magma effusion rates, temperatures and compositions, and lava rheologies. The modeling objectives were to develop physical models of the enlargements of cracks caused by hydrodynamic, acoustic and thermal effects of the ascending magma, multidimensional and nonisothermal magma ascent in volcanic conduits, viscoplastic behavior of magma and lava in the presence of melting and solidification and gas exsolution, and local and global lava flow.

The work on the project involved the definition of eruption data, eruptive cone and fissure distributions, development of thermal and rheological instrumentation, field work to establish thermal and rheological data, measurement of physical properties of Etna's rocks, development of magma ascent and lava flow physical models, definition of internal system, and an assessment of the volcanic hazard at Etna.

The data definition involved structural trends, frequency and spatial distributions of historical eruptions, cones and fissures, distribution of earthquake epicenters, internal structure of the volcano, global lava flow morphologies, local structures of lava flows related to ephemeral mouths, lava channels and tubes, and chemical and volcanological data involving recent eruptions of Etna. The lava flow instrumentation work involved the construction and laboratory and field testing of a shear vane viscosimeter suitable for establishing the rheology of lavas. The viscosimeter and its supporting system were successfully tested at Kilauea and proved that they can be used during the future eruptions of Etna. Laboratory testing of rock samples from Etna was conducted in a fracture mechanics laboratory to determine their physical properties and crack propagation characteristics. Instrumentation to measure thermal properties of lavas was designed but not field tested.

The internal system of Etna was constrained by using the available geological, geophysical and volcanological data, and a one-dimensional and isothermal magma ascent model to study two limiting eruptions of Etna. This modeling effort demonstrated the importance of gas loss to fractures from the ascending magma, and the relaxation characteristics of the volcanic edifice which control

eruptions from a central conduit or from eccentric subvertical or subhorizontal fissures. Data and physical modeling suggest that the volcanic edifice of Etna is comprised of a structurally weak zone situated from 1-4 km below the summit, and of a central conduit fed by shallow (8-10 km) and deep (about 20 km) magma storages. A nonisothermal and two-dimensional magma ascent model with melting and solidification of conduit walls was also developed which justified the utility of using a one-dimensional and isothermal modeling approach in studying magma ascent at Etna. The results from this two-dimensional modeling effort showed that the gas exsolution can be very effective in keeping the internal flow of magma hot and that, therefore, magma may ascent along very narrow and long conduits. A viscoelastic structural mechanics analysis of the volcanic edifice of Etna was also carried out which demonstrated that the cracks at depth prefer to propagate subvertically, whereas in the superficial regions of the volcano they prefer to propagate subhorizontally, implying that the fissures should be produced along the directions of preferential crack propagation.

The effects of crystallization in lava, formation of lava tubes, and determination of secondary vents were studied by developing local lava flow models. A three-dimensional lava flow modeling effort was also initiated to better understand the lava dome, head, and flow margin formations. Heat transfer from lava to the atmosphere was also studied and it was established that the morphology of the lava surface changes the radiative properties of the surface and therefore the heat transfer, and that the convective heat transfer is small in comparison to the total heat transfer from the lava to the atmosphere. Three- two- and one-layer global lava flow models were also developed and tested with data from Etna and Kilauea using different rheological laws. This established that multilayer lava models are computationally very intensive and that they require more precise physical and rheological properties of lavas which are in general poorly constrained. By including two-dimensional lava flow effects into a simple global lava flow model with a Bingham rheology proved to be very effective in performing lava flow simulations involving long emplacement times and flow lengths, and in reproducing some well-defined lava flows from Etna and Kilauea. Effective lava flow simulations also require smooth topographies of the volcano, and for this purpose a methodology was developed which mathematically reconstructs the surface of the volcano from digitized topographic maps. Such a topography, when combined with a global lava flow model, is useful to perform lava flow hazard assessments.

Lava flow hazard assessment at Etna was not as successfully accomplished as planned on the project for several reasons: (1) an effective global lava flow model was not developed and tested until very late into the project and more work is needed to integrate this model with the actual topography of the volcano, and (2) future vent openings data were not appropriately processed for use in lava flow simulations. These and other tasks could have been accomplished much more successfully if no modifications of initial project responsibilities occurred as discussed in the modifications and acknowledgements section of the report.

The magma and lava flow modeling project was defined as an interdisciplinary project with well-defined tasks involving naturalists and physical scientists with different cultural backgrounds. The project received only a fraction of the total funding of the Etna Laboratory Volcano Project, but its benefit to cost ratio is very high. The project produced significant advances in physical modeling of magma ascent and lava flows and important cross-cultural exchange of information, but no important advances in statistical processing of geological and volcanological data required for effective physical modeling.

The project demonstrated that the understanding of volcanic processes and assessment of volcanic hazard must be based on an interdisciplinary work of researchers able to work toward a common goal where the project management becomes very time consuming, difficult, and unpopular. There was virtually no interaction between this project and other projects of the Etna Laboratory Volcano Project although specific work tasks with assigned responsibilities to accomplish this interaction were structured into the project. This indicates that the success of an interdisciplinary project depends on the project team members who can deliver on their responsibilities and on a competent technical coordinator whose recommendations to CEC are respected.

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