Research on Volcanic Hazards in Europe

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Volcanic eruptions have been a threat throughout the history of the populations of many European countries, mainly those around the Mediterranean Sea. This area, according to the theory of plate tectonics, is the fragmented boundary between the African and European plates. The different motions of the two plates cause a continuous buildup of energy, which is released by earthquakes and dissipated in the formation of magmas. Viscous magmas rising through localized fracture systems may produce violent, explosive eruptions that, although less frequently than high-magnitude earthquakes, kill people and cause serious damage. Volcanoes of Italy and Greece have erupted about 140 times since the big eruption of Santorini in the Aegean Sea in 1500, B.C. which probably contributed to the disappearance of the Minoan civilization of the island of Crete.

Italy is at present the country for which the volcanic risk (defined as the probability of a volcanic event in a given time interval multiplied by the expected damage) is highest, owing to the high population density on active volcanoes. The extreme case is the town of Naples, where about 2 million people live under the combined menace of two volcanoes (Mount Vesuvius and Phlegraean Fields) that have in the past produced ravaging explosive eruptions after hundreds or thousands of years of rest. Although Mount Vesuvius, which last erupted in 1944, does not show any sign of renewed activity, the Phlegraean Fields caldera has been in a state of unrest since 1970, with a peak ground upheaval of about 3 m and sporadic earthquake swarms. A deep borehole drilled for geothermal energy found a temperature of 420°C at about 3 km of depth, possibly indicating a nearby hot magma body (*1*).

Active volcanoes exist also in Greece, Turkey, the Atlantic islands which are politically part of Spain (the Canary Islands) and Portugal (the Azores), and Iceland. France has active volcanoes in some of its overseas territories, like the French Antilles and Réunion. Even countries that do not have volcanoes in their territories have been subjected to the effect of volcanic eruptions. For example, archeological evidence shows that large areas of northern England, Scotland, and Ireland were laid waste by falling volcanic ash from an Icelandic eruption.

Dangerous flows. (Left) During the 1983 eruption of Mount Etna, an artificial explosion diverted the lava into a new course. [Gianni Torto/Photo Researchers] (Right) Volcanologists and civil protection soldiers preparing the blasts along the lava from the May 1993 eruption of Mount Etna. [Courtesy of Franco Barberi]

For all these reasons, volcanological research is vigorous in almost all the European countries in a joint effort to mitigate volcanic disasters. Most of the field researchers from all over Europe concentrate on Italian volcanoes. The present situation of Italian volcanoes is the following: Besides the Phlegraean Fields, indications of a state of unrest exist also at the island of Vulcano (in the Aeolian Islands), where the gas emission in the active crater is continuously increasing, gas temperatures are over 600°C, and the gas composition suggests the presence of a magmatic source (*2*). The volcano of Stromboli continues the activity at its summit craters with no major interruptions and is not a source of worry. Mount Etna started a major eruption 2 years ago with an abundant outpouring of fluid magmas that ran along the eastern slope of the mountain forming slowly advancing lava flows.

The phenomena that should occur before eruptions, such as small earthquakes, tremors, and changes in the composition of fumarolic gases, are being monitored on all of these volcanoes with increasingly sophisticated techniques by several institutions. The highest quality data on precursors are those collected at the Phlegraean Fields, which include seismic data, ground deformations, gravity variations, and gas geochemistry. The ground upheaval occurred in two pulses separated by 10 years of slow subsidence. The most recent pulse finished in 1985, and since then, the ground has been sinking slowly again.

Physical modeling suggests that ground movement cannot be solely ascribed to the effect of a magmatic intrusion, a part of it must be connected with the heating of shallow rocks and aquifers (*3*). Analysis of the dynamics of the Phlegraean Fields, by usual methods of nonlinear forecast (*4*), suggests a chaotic, low-dimensional behavior, which is predictable, on a time scale of days.

Progress in the study of precursors on many volcanoes of the world is showing that they are related to eruptions in an elusive way and that they may precede a major eruption by only a few days or less. Hence, in a densely populated area, a real mitigation of the risk can be achieved only through long-term programs that are based on the knowledge of the past behavior of a volcano, on its present structure and morphology, and on the simulation of possible future eruptions.

Several European groups have been working on the physical and numerical modeling of the processes occurring in a magmatic reservoir (*5*), the flow of magma in a conduit (*6*), and the magma after it has erupted from the vent (*7*). Although the use of these models is severely hampered by the uncertainities in the knowledge of many parameters (temperature, pressure, viscosity, volatile content of magma in a pre-eruptive stage, size, shape, and depth of magma reservoirs, and so forth), they can show how the mechanism of an explosive eruption can be inferred from the study of the deposited products and the conditions ruling the different types of eruption.

A decrease of volcanic risk can also be achieved by intervention during eruptions, as was done during the recent eruption of Mount Etna. After 23 months of rest, Mount Etna began a new eruption on 14 December 1991. Two fractures opened at 3000-m elevation, and one of them propagated southeast down to 2700 m. Lava began to pour out from the lowest end of the fracture. Simulation of the most probable paths of the lava indicated that the village of Zafferana Etnea,

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with 7000 inhabitants, was at risk.

Several actions were undertaken to protect the village. A 234-m-long and 21-m-high dam was built out of 370,000 m^3 of earth, scoriae, and stones. The dam contained the lava and was breached after about 1 month. Three additional smaller earthen barriers were built to slow the flow toward Zafferana.

The main effort consisted of several attempts to stop the advance of the lava front by the diversion of the flow out of its natural and extensively tunneled channel. The main intervention was made at an elevation of 2000 m in an almost inaccessible zone with the extensive use of helicopters. Initially an attempt was made to plug the entrance of a tunnel by dumping concrete blocks, antitank obstacles (hedgehogs), and blasted portions of a solid levee into it. The interventions caused the partial obstruction of the tunnel, which made part of the lava pour out into the adjoining Valle del Bove, with the consequent halt of the advancing front. However, benefits lasted only 2 weeks, after which the lava started again its slow advancement toward the outskirts of Zafferana.

The final successful intervention was carried out from 27 to 29 May. An artificial channel was dug departing from the natural one. The solid separation levee was thinned to 3 m and blasted by 7000 kg of explosive. Two-thirds of the lava then spontaneously flowed into the artificial channel. A total diversion was obtained when the tunnel was plugged with 230 m^3 of lava boulders. The lava front, only 850 m from Zafferana, stopped at last. In June 1992, the effusion rate was halved from 30 to 15 m^3/s, and with the reduced thrust, the lava was no longer capable of long-distance runs (8). The eruption ended on 30 March 1993 after 473 days of continuous lava flows. It was probably the largest eruption of Etna in the last 300 years, covering about 7 km^2 with more than 250 million cubic meters of lava.

The European Science Foundation has recently promoted a scientific program, called EVOP (European Volcanological Project), that gathers all the expertise spread across Europe and focuses it on the knowledge of the internal plumbing system of volcanoes, the mechanism of eruptions, and eruption forecasting. One major problem of volcanological research is that volcanoes are different in terms of plumbing systems and active behavior; therefore, transfer of knowledge from one volcano to another is not straightforward. Europe has the advantage of the availability of a virtually complete spectrum of volcano types in different structural settings. Six were chosen as laboratory volcanoes with the rationale of covering that spectrum as widely as possible. They are Mount Etna (Italy), Krafla (Iceland), Piton de la Fournaise (Réunion Island, France), Teide (Canary Islands), and Furnas (the Azores, Portugal). The project includes the formation of a multidisciplinary team of volcano experts for immediate response to a volcanic alert.

Although advances have been made in Europe, some methodologies are still waiting to be used at their full potential, even on such threatening volcanoes as Mount Vesuvius and Phlegraean Fields. High quality seismic exploration, such as that employed for oil research, advanced seismic tomography, and deep drilling, are necessary to improve our knowledge of these volcanoes.

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Evolving in a Dynamic World

Andrew F. Read and Paul H. Harvey

In the 1980s, a new prominence for organismic biology was marked by the emergence of behavioral ecology, a field spearheaded by two British biologists, J. Krebs and N. Davies. Behavioral ecology consists in large part of applying optimality models to help understand why animals behave as they do. Those models often depend on the frequency of certain reproductively significant events, but recent work suggests that this evolutionary approach may profitably be broadened into the ecological domain by incorporating density as well as frequency dependence.

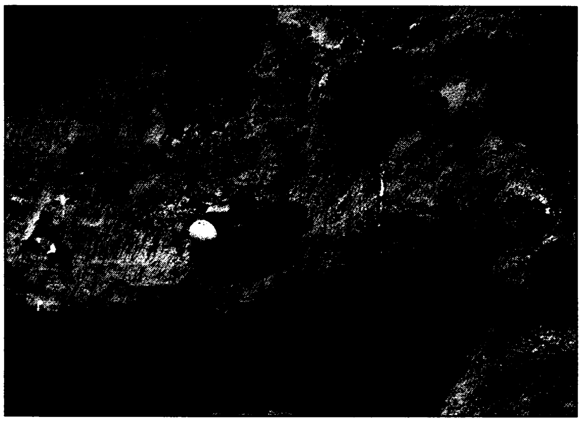

Fig. 1. A bad egg. A female white-fronted bee-eater removing from her nest an egg that had been "dumped" there by another female bee-eater. Intraspecific parasitism, or dumping, in this species was described by Emlen and Wrege (*13*). [Photograph by Marie Read]

Behavioral ecology often demonstrates that the evolutionarily favored behavior for one individual in a population depends on how other individuals are behaving. Eventually, populations of individuals will end up behaving according to an evolutionarily stable strategy (ESS), that is, one that cannot be invaded by others. For example, an ESS analysis, as developed by J. Maynard Smith (University of Sussex) and G. Price (University of London), for understanding why animals do not always escalate fights (*1*) depends on defining a set of available strategies and then seeing which strategies persist at equilibrium after specifying an optimization principle and a starting point. This approach has unraveled several biological conundrums, including aspects of aggressive behavior, parental care, sex allocation, mating systems, foraging, and brood parasitism (*2*). But there has always been unease. For example, there is the problem of genetics or, as Liverpool University's G. Parker put it, "Whether all the alternative strategies can ever exist in a heritable form in real populations is an important question, but," he added comfortingly, "that should not deter us from considering what would happen if they could" (*3*)! Just as behavioral ecology must take on board genetic realism in order to broaden its scope, so it cannot much longer ignore population dynamics. The fitness costs and benefits of many reproductive strategies are likely to be density- as well as frequency-dependent.

Intraspecific brood parasitism, a topic increasingly studied by behavioral ecologists (*4*), illustrates the possible importance of both density and frequency dependence in ESS studies. Brood parasites, typically birds

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