Distant Effects of Volcanism—How Big and How Often?

Tom Simkin

What do an archaeological dig, a leaf imprint, a stratospheric circulation model, and a Greenland ice core have to do with a large volcanic eruption in ancient Japan? Volcanologists studying the eruption's deposits can measure its size, but its date may be known only to the nearest century. Archaeologists digging at the base of the ash, however, find leaves that accurately identify the eruption's season, and that is just what the meteorologist needs to assess the likelihood that its fine aerosol could have been transported to Greenland and preserved there as an acidic annual layer in an ice core. As reported elsewhere in this issue, glaciologists studying a new 3053-m core (*1*) have used such varied information from disparate fields not only to date the eruption more precisely but also to use that layer to calibrate other cores and build a better chronology that can, in turn, link with tree-ring, oxygen isotope, pollen, varve, and other chronologies to illuminate climatic fluctuations of the past. This scenario illustrates the excitement of interdisciplinary convergence in contemporary volcanology.

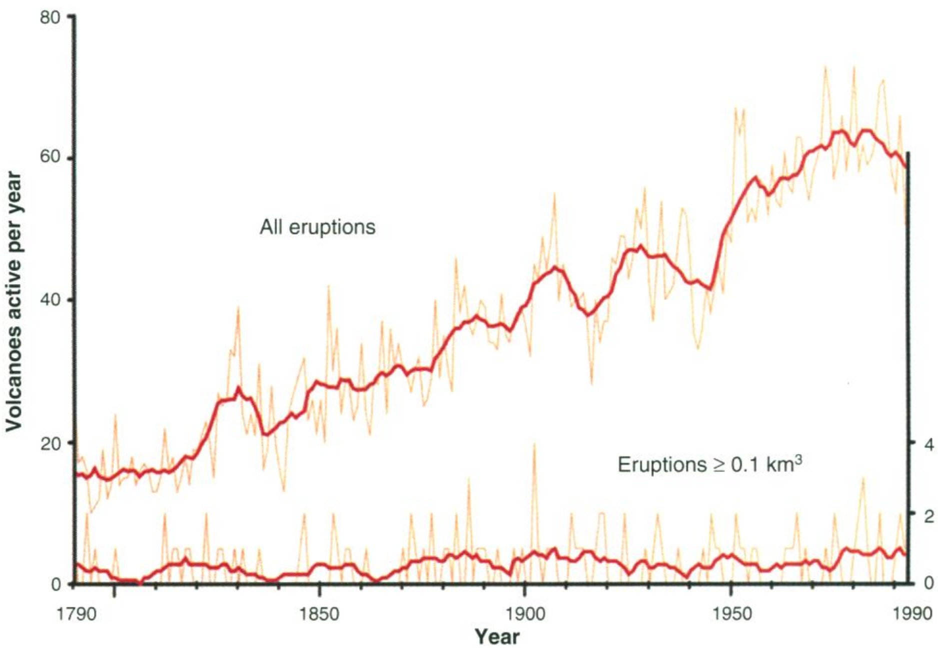
The record of past eruptions is important because large eruptions are sufficiently varied and sufficiently uncommon that to understand them (and prepare for them), we must make the most of the historic and recent prehistoric record.

Major explosive eruptions cause short-term climate change when their gases, if sufficiently voluminous and blasted high enough into the stratosphere, form a widely dispersed aerosol of sulfuric acid (H_2SO_4) droplets. This fine mist acts as a filter, partially blocking solar radiation from reaching Earth's surface. The 1815 eruption of Indonesia's Tambora, history's largest, is widely believed to have caused June snowstorms in New England and severe crop failures at high latitudes during the following "year without summer." The substantially larger eruptions of prehistory call attention to volcanism as an important natural agent of climate change (*2*).

But volcanism has other significant impacts as well. In 1773–74, fluorine-rich gas, ash, and rain destroyed crops and poisoned livestock throughout Iceland, killing 24% of the human population by starvation. One hundred years later, the Krakatau tsunamis (up to 40 m in height) killed over 34,000 people, including one as far away as Ceylon. Pumice from Krakatau floated in the Indian Ocean for 2 years, disrupting shipping at times and transporting organisms to distant shores. More recently, air transport has been affected when, on at least seven occasions, jumbo jet engines failed upon entering ash clouds. Two million years ago (just yesterday to geologists), a Yellowstone eruption produced 2500 km^3 of tephra in a matter of hours. Its effect on climate must have been substantial, but the sheer thickness of distant ashfall—covering 16 states and exceeding 20 cm at distances of 1500 km—would be considerably more than a nuisance if it were to be repeated tomorrow. Yes, we need to know more about these significant perturbers of our world.

Our record of historical volcanism (see figure) shows a dramatic increase over the last two centuries that is apparent rather than real (*3*). It is closely proportional to the increase in global population during that same period, and it spans huge advances in communication, transportation, and recordkeeping. The two largest drops in apparent volcanism coincided with the two World Wars, when observers (and editors) were preoccupied with other things. And the larger eruptions—less likely to be missed—have been relatively constant through the last two centuries. Volcano watchers like to think that we have been capturing most eruptions since regular reporting started in the 1960s (yearly by the Volcanological Society of Japan and monthly by the Smithsonian), but we know we are still missing some. Even the record of large eruptions decays rapidly from the average shown in the figure of more than five per decade in recent centuries to 0.7 per decade before the global exploration and printing advances of the 15th century. Deep submarine eruptions are far more voluminous but are rarely documented even today. The hard fact is that our historical record of volcanism, beyond the last 100 to 200 years, is poor for most parts of the world, and in only a few of these has careful fieldwork, with lab dating of young products, filled in much of the record (*4*).

In recent decades, though, eruptive products reaching the stratosphere have been sampled by aircraft and balloon, analyzed for total SO_2 content by satellite, and measured for altitude and thickness by laser imaging. These results, on the moderate as well as large eruptive clouds of recent decades, have greatly advanced understanding



Volcanism through time. Shown are the total number of known volcanoes erupting per year (thin upper line) and a 10-year running mean of the same data (thick upper line) obtained from eruption reporting since 1790 A.D. (*3*). Lower lines show only the annual number of volcanoes producing large eruptions (≥ 0.1 km^3 of tephra or magma); scale is enlarged (on right axis). Thick lower line again shows 10-year running mean.

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of volcanism's far-reaching effects. It is now clear that total SO_2 is at least as important to climatic impact as eruptive volume, the traditional volcanological measure of eruption size and the only one that can be conveniently estimated for ancient events. Furthermore, these two measures are not always correlated, and several high-SO_2 eruptions of modest size have put up significant stratospheric aerosols (5). These findings complicate attempts to evaluate climatic and other impacts of ancient eruptions.

But all these complications and weaknesses in the record help to underscore the importance of alternative approaches from other disciplines to the building of a reliable chronology of global volcanism. The H_2SO_4 aerosols eventually settle to Earth, and pioneering work by Danish glaciologists in the 1970s (6) showed that the resulting acidity layers in deep ice cores from Greenland provide a volcanic chronology. American and French groups found the same evidence in Antarctica and, by correlating several layers and confirming the common composition of their (rare and tiny) volcanic glass fragments, showed that some eruptions have a truly global distribution of products (7). These results have continued, through painstaking work on ever more cores, and the report by Zielinski *et al.* discusses results from the newest and deepest Greenland core (1). The authors suggest more accurate dates for several large eruptions and provide many new dates (particularly before 0 B.C.) from unknown sources. The largest signal in the last 7000 years, also detected in Antarctic cores (7), was from an unknown source around 1258 A.D. However, four larger signals were found in the 7th millennium B.C., marking this as easily the most volcanically active part of postglacial time.

The new results are exciting to all scientists interested in the volcanological record. The principal problem of this approach, however, is that aerosols move swiftly eastward around the globe but their latitudinal spread is relatively slow. This means that an eruption from high north latitudes (Iceland, Alaska and Kamchatka) leaves a relatively large volcanic deposit on Greenland, whereas a comparable one from low latitudes leaves a much smaller record, and one from the Southern Hemisphere may leave none at all. Until more cores are obtained from mid- and low-latitude sites (not famous for their stable glaciers), substantial uncertainty will surround the identification and calibration of eruptive sources. Added to this problem is the danger of misinterpreting the completeness of volcanism's recent historical record. Very large eruptions may well have been missed only a few hundred years ago in some parts of the world, so the matching of sulfate spikes with poorly constrained dates from the volcanic record needs caution. Nobody should be surprised to learn tomorrow of a previously unreported larger eruption around that same time from another part of the world.

The ice core approach is enormously exciting, however, and holds great promise. The pieces of a large puzzle seem to be falling into place. The linking of these results to proxy records of past climate, such as tree-ring chronologies (8), offers the opportunity to refine both volcanic and climatic chronologies while gaining a more profound understanding of the relation between volcanism and climate change.

References and Notes

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Folding Pattern Diversity of Integral Membrane Proteins

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Membranes consist of phospholipid bilayers that are highly insulating and confine cells and subcellular compartments. Solute transport, signal transduction, and energy conversion across these barriers are catalyzed by proteins that traverse the hydrophobic core of the membrane (a width of about 30 Å). The surface of these proteins that interacts with the membrane core is also hydrophobic, a property that distinguishes these proteins from globular ones and causes them to aggregate in aqueous solution (unless amphiphiles such as detergents are used to replace the lipids). At the boundaries between the lipidic and aqueous compartments, these proteins contact the polar head groups of the phospholipids. Beyond, they may exhibit domains of various sizes, which are exposed to the aqueous phase.

The number of times a polypeptide spans a membrane varies from one to perhaps two dozen times. Of the few proteins for which structures have been determined at high resolution, the domains within the membrane exhibit rather simple topologies, suggesting that structure prediction of the integral membrane domains of these proteins should be straightforward. There are fundamental limitations to the applicability of the methods currently in use, however, and these, together with ways to overcome them, are discussed here.

Bacteriorhodopsin provided the first glimpse into the organization of a polypeptide in a membrane (1) (panel A in the figure). Its seven transmembrane α-helical segments each consists of ~25 hydrophobic residues. They expose hydrophobic surfaces in the membrane core and allow the hydrogen bonding potential of the backbone to be saturated *within* each segment (panel B). The structure suggested a prediction algorithm (2) that is now applied routinely to obtain structural models of transmembrane proteins and that identifies potential membrane-spanning segments on the basis of the existence of hydrophobic stretches, allowing protein sequence data banks to be scrutinized rapidly. When the structure of a photosynthetic reaction center was solved to atomic resolution, the prediction fitted the structure well (3). As a consequence, membrane-spanning proteins are now generally conceived as containing long, hydrophobic α helices. This concept also suggests an attractive mechanism for membrane insertion and secretion by partitioning (4). This algorithm has been diversified (5) and complemented by the finding of asymmetrical distributions of residues (for example, positive charges inside) in α-helical membrane-spanning segments (6). This rule helps to define the ends of such segments

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