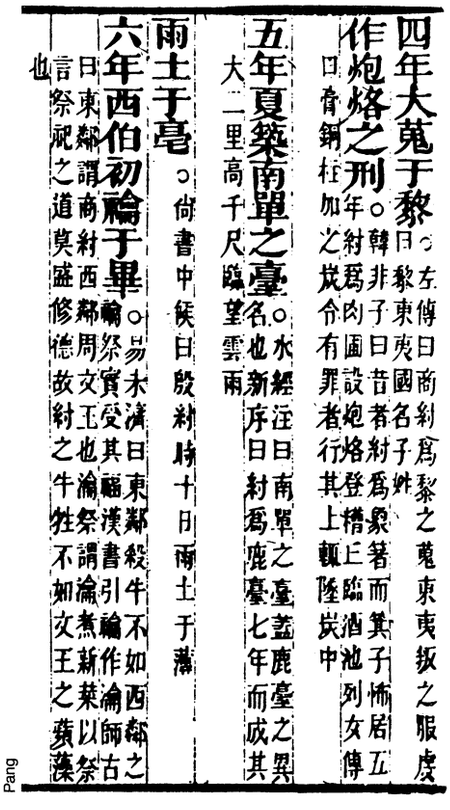
Excavating Words: A Geological Tool

Human histories unravel geological mysteries

By STEFI WEISBURD

"Among events of divine ordering there was ... after Caesar's murder [March 15, 44 B.C.] ... the obscuration of the sun's rays. For during all that year its orb rose pale and without radiance ... and the fruits, imperfect and half ripe, withered away and shriveled up on account of the coldness of the atmosphere." — Plutarch, *Caesar* (circa A.D. 100)

From the Chinese chronicles of the Han dynasty: 43 B.C., third month, *"It snowed. Frosts killed mulberries."* Fourth month, *"the sun was bluish white and cast no shadow. At high noon there were shadows but dim."* Ninth month, second day, *"Frosts killed crops, widespread famine. Wheat crops damaged, no harvest in autumn."*



Pang

This excerpt from Chinese records notes observations that researchers believe are related to the 1120 B.C. eruption of the volcano Hekla in Iceland. On the left is a passage from The Bamboo Annals (written on bamboo because paper had not yet been invented), which were unearthed in the Wei tomb in A.D. 281 and buried at least five centuries earlier. It reads: "Fifth year of King Chou [the last king of the preceding Yin dynasty] it rained dust at Bo."

Geologists today learn about the history of the earth primarily from the physical clues left by volcanos, earthquakes and other forces that have sculpted the face of the earth. By knowing how to read the geological records — from the layers of sediment containing ancient fossils to the geochemistry of lavas — scientists can often reconstruct geological events that took place hundreds of millions of years ago.

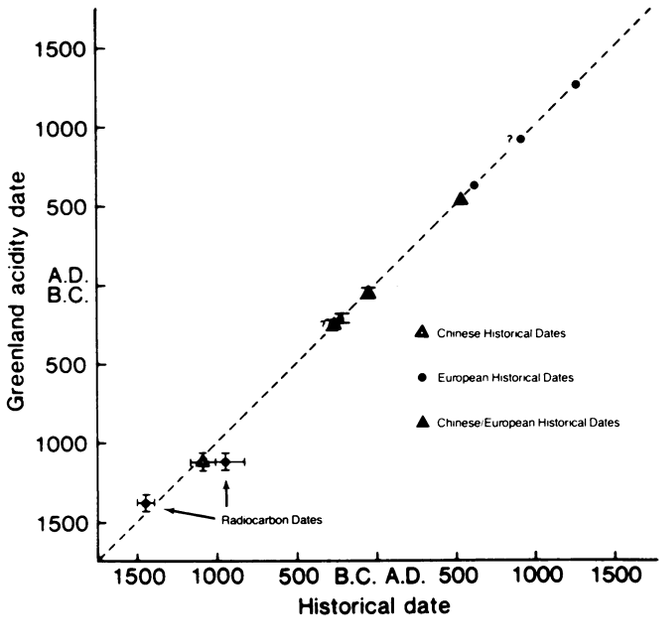
But for volcanos and a number of other geological and astronomical phenomena that occurred during the last three or four millennia, there exists yet another source of information: the written records left by ancient peoples. Researchers have found a treasure trove of data — like the two passages at left — in the thousands of volumes of poetry, plays, biographies, histories and official documents left by ancient civilizations ranging from the Egyptians, Romans and Greeks to the Japanese and Koreans. Most recently, the scientific community has gotten a glimpse at the vast and detailed chronicles of the Chinese dynasties, which began in 2200 B.C. to commission astronomers and others to record officially their scientific observations.

By looking through the eyes of the ancients, scientists today can mold the historical accounts of astronomical observations, earthquakes, volcanos, weather and food production into a reconstruction of the geological past — and sometimes do it with greater precision than that allowed by the physical data. In this way, historical documents detailing volcanos and their aftereffects are not only helping in the study of the frequency and distribution of past volcanic eruptions but also adding much-needed data to the modeling of climate changes that might result from very large volcanos, or perhaps from a nuclear war.

"The volcanos that have gone off in the last 100 years, where the temperature records have been the best, have been relatively small compared to some of the big ones discussed in the historical literature," says Michael R. Rampino, a geologist at the NASA Goddard Institute for Space Studies in New York. At most, volcanos in this century have caused short-term cooling of a few tenths of a degree — an amount comparable to interannual variations and not large enough to put the climate models to the test, he says.

Rampino is among a few researchers in the United States interested in using historical texts as scientific tools. He teamed up with Richard B. Stothers, an astronomer with a background in the classics, also at NASA Goddard, who has been cataloguing and interpreting ancient Mediterranean writings over the last 10 years. The researchers have also rid many compilations of translation errors and misprints that have plagued such texts over the ages. Stothers discovered, for example, that an eruption cited in modern work to have occurred in the year 604 had been mistranslated from a German book that had referred to a volcano on *page* 604. Moreover, in three recent compilations, Stothers and Rampino found that for Mediterranean eruptions within the period 1500 B.C. to A.D. 630, erroneous or omitted dates were more numerous than correct dates by about 50 percent.

Stothers especially has spent many hours in the New York Public Library and the Columbia University Libraries poring through an equivalent of a quarter of a million pages of English text. With the exception of classical treatises on rhetoric and some Christian hymns, the researchers believe they have covered all of the extant European literature for the time period 700 B.C. to A.D. 630. The most useful and numerous European records of natural events, says Rampino, are from classical times. The Romans in particular took special care to write about portents, which were often based on weather conditions or the stars. There is far less valuable material from the Middle Ages, and the record from before 700 B.C., based mostly on



Stothers/SCIENCE, modified by Pang

There is a very good correspondence between the dates of volcanic eruptions as determined from historical records and those measured by acidity peaks in Greenland ice cores. Here the historical date (from reports of "dry fog," adverse weather and observations of eruptions) is plotted against the Greenland date for very large explosive eruptions that occurred between 1500 B.C. and A.D. 1500. Radiocarbon dates are also included. Horizontal and vertical lines are "uncertainty bars"; actual dates could fall anywhere between them. Question marks at 270 B.C. and A.D. 934 indicate times in which abnormally cold weather was reported but no other symptoms of volcanic eruptions such as "dry fogs" were noted. They also occur during times that were poorly chronicled in general.

legends, is not very reliable.

Less scrutinized are the Chinese documents, which are far more voluminous than the European records. Modern China has been so torn by civil wars and cultural revolutions that a careful scientific analysis of the dynasty chronicles and other records was not possible until about a decade ago, says Kevin D. Pang, an astronomer at the Jet Propulsion Laboratory/California Institute of Technology in Pasadena. "There are rooms and rooms of documents and we've only begun to scratch the surface," he says. Pang works with Hung Hsiang Chou, a professor of Chinese language and culture at the University of California at Los Angeles.

When they search historical literature, Pang, Stothers and others look not only for direct observations of volcanic eruptions but also for passages like the above excerpts from Plutarch and the Han dynasty chronicles. These two entries, made on opposite sides of the globe at about the same time period, describe the classic signature of a large volcanic eruption: a strange veiling of the sky followed by unusually cold weather that kills the crops. The veil, called "dry fog" by Benjamin Franklin after the 1783 eruption of the Laki volcano in Iceland, is a mist of sulfur aerosols spewed out with silicate ash during an eruption and carried by the atmosphere to girdle a hemisphere, or in some cases the entire planet. The volcanic particles absorb and scatter back radiation from the sun. This causes the sun, moon and stars to appear dim — an effect thought by some cultures to be an omen of foreboding. This interpretation was often justified, because the aerosols, by backscattering the solar energy, produced colder temperatures that led to failed crops and sometimes starvation.

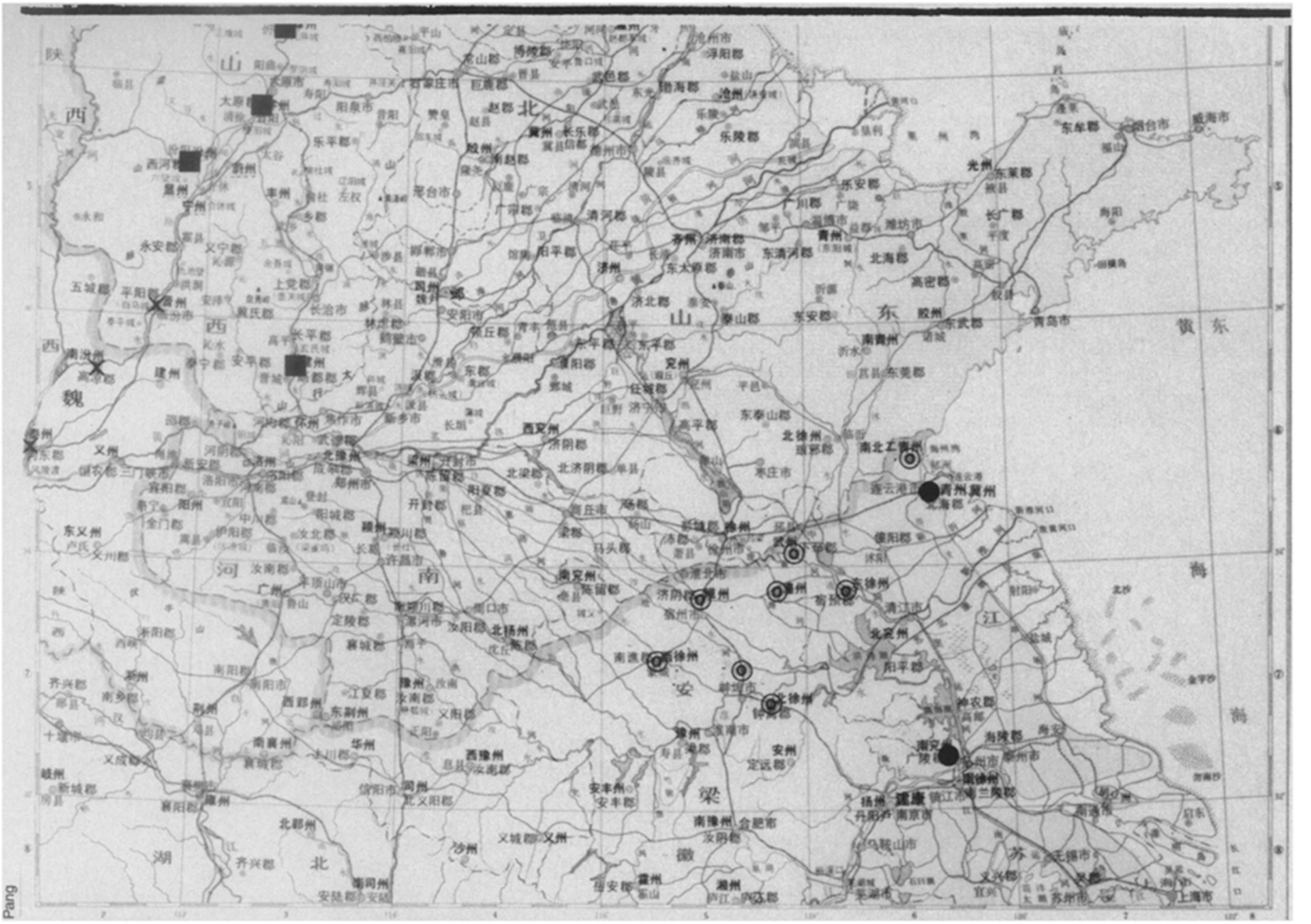
With the excerpts from Plutarch and many others, Stothers and Rampino were able to pinpoint the eruption date of this particular volcano to 44 B.C. They also suspect that the volcano was Mt. Etna in Sicily, for like others, Vergil wrote: *"After the death of Caesar ... how often we saw Etna flooding out from her burst furnaces, boiling over the Cyclopean fields, and whirling forth balls of flame and molten stones."*

This is one of the cases in which the historical information is more precise than the physical evidence. Five years ago, a group of researchers at the University of Copenhagen in Denmark detected a strong peak in the acidity level in a layer of Greenland ice. Such peaks are thought to result from the volcanic emission of sulfur dioxide gas, which reacts in the atmosphere to form sulfuric acid. This acid, spread by the atmospheric winds, became incorporated in the Greenland snow. By counting the layers of ice deposited every season since then, the researchers could estimate only that the sulfuric acid had been laid down anywhere from 80 to 20 B.C. Moreover, there was little way to determine from these data alone the origin of the eruption; the volcano could have been small and close to Greenland or large and far away. Radiocarbon dating of the lava flows at Mt. Etna were even more uncertain — eruptions dated at 890 B.C. and A.D. 110, 140 and 190 all have mean errors of about ±100 years. The historical documents provide a way to calibrate the ice core data, says Stothers, so that the people doing ice core analysis now have benchmarks for their samples.

One of the disadvantages of using historical data is that the ancient descriptions of volcanos are often less quantitative than modern measurements. Nonetheless, Stothers and other reseachers have been able to get a feel for the duration and magnitude of a number of historic volcanic eruptions and their aftereffects. The best-quantified case, says Stothers, is an eruption in A.D. 536, which also turns out to be largest eruption whose effects have been quantified in the last 10,000 years. The effects of the 536 volcano far exceed those of the eruption in 1815 of Tambora (Indonesia), a volcano that discharged 10 times the amount of pyroclastics (fragmental volcanic material blown into the atmosphere) as the Krakatoa eruption in Indonesia in 1883 (SN: 8/27/83, p. 139).

According to Stothers, four reliable European descriptions of the resulting "dry fog" cloud exist. A Byzantine historian named Procopius who lived in Rome at the time wrote that *"the Sun gave forth its light without brightness, like the Moon, during this whole year, and it seemed exceedingly like the Sun in eclipse, for the beams it shed were not clear nor such as it is accustomed to shed."* A later chronicler says that darkness lasted for 18 months and each day the sun shone for only four hours. By noting the positions of each of the four writers and the number of hours of sunlight, Stothers estimated the amount of attenuation of the light by the cloud. He calculated an optical depth, or a measure of the light's attenuation as it traveled in a vertical path, of about 2.5 — which means that at maximum altitude both the sun and a full moon would have appeared about 10 times fainter than normal. By comparison, the optical depth of the Tambora eruption was estimated to be 1.3 and that of Krakatoa to be 0.5.

To check his calculation, Stothers compared the magnitude of a Greenland ice acidity peak thought to correspond to the 536 eruption (it had been dated A.D. 540 ± 10 years) with that of other eruptions such as Tambora for which the optical depth was more accurately known. In this manner he obtained an optical depth of 2.2, which is fairly close to his previous esti-



This map of the Yellow River and Yangtze River regions in China shows areas where frost, drought and famine were reported after the A.D. 536 eruption of a volcano located probably to the southeast in New Guinea. Squares denote reports of early frost, drought and famine in A.D. 536; crosses denote reports of frost in A.D. 536; solid circles show where summer snow and famine were recorded during A.D. 537; and double circles denote famine in A.D. 538. The higher latitude spots in the Wei kingdom felt the chilling effects of the volcano earliest because the climate there is more sensitive to temperature changes than in the lower Liang kingdom.

mate.

The effect of this volcano was also felt in China. Pang reports that, during the spring and fall equinoxes each year, the ancient Chinese looked for Canopus — the brightest star in the constellation of Alpha Carina — to assure themselves of good times ahead and to demark the seasons. In A.D. 536, however, Canopus was not seen. Pang found records from the state of Ching in southern China reporting frost and snow in July and August that killed the seedling crop, causing a major famine the following autumn. The accounts also show that the effects of the eruption were noted until 538. Other kingdoms reported similar disasters; one record indicated that the weather was so severe that 70 to 80 percent of the people starved to death, says Pang.

Pang, Stothers and Rampino all suspect that the volcano responsible was Mt. Rabaul on the island of New Britain in Papua New Guinea. Their belief is based on the fact that the more southerly latitudes near the Mediterranean experienced thicker and more prolonged haze, implicating a volcano in the tropics. A Rabaul site is also consistent with the fact that monsoon winds blow toward China from New Guinea at that time of year. Radiocarbon dating of the lava at Rabaul places an eruption at 540 ± 90 years. Unfortunately, says Rampino, we cannot yet tell from the geological data taken near Rabaul whether the volcano was very large, or just particularly sulfur rich. "We don't have any of the distal [distant] ash, we only have pyroclastic flow around the volcano, so we don't know how much of the stuff went up in the atmosphere and then fell out.... [In the future] we'd like to get some good samples of deep sea cores in that area to see if we can find an ash layer on the ocean bed that correlates with the 536 eruption."

One of the oldest volcanic eruptions to be studied through historical literature is placed at 1120 B.C. ± 50 years by ice core acidity measurements. Scientists, believing that the Icelandic volcano Hekla is responsible for that acidity peak, have obtained a time of eruption of 950 B.C. ± 130 years using radiocarbon dating at the volcano. Pang and Chou have found accounts in the Chinese record of the volcano's effect that report unusually long dust storms of gray ash. In *Lu Tao,* a Zhou dynasty book, the researchers read that one foot of snow fell in the sixth month and that the crops didn't ripen. "In China, snow in the sixth month is like our expression once in a blue moon," says Pang. "This is especially true because we know — based on the fact that elephants and rhinos were seen on the banks of the Yellow River — that the climate in China at that time was much warmer than it is now."

Since most reports of these events were written long after 1120 B.C. by chroniclers compiling all the happenings that had occurred in the previous dynasties, Pang feels that they can't be completely trusted. So he and Chou turned to the only written records from that time — oracle bones, radiocarbon dated before the Zhou dynasty at 1095 B.C. ± 90 years. (Paper had yet to be invented.) As a means of fortune-telling, questions about the future were carved into these oracle bones — made of turtle shell or oxen bone — and the answer was thought to depend on how the shell or bone cracked when exposed to heat. Chou

went through 100,000 pieces of oracle bones, noting all the questions potentially relevant to volcanos.

Some of the oracle bones dated around 1120 B.C. alluded to the fact that there was a year without harvest, that the seedlings died and that the Chi — the sacrificial ceremony — was performed throughout the land. Pang believes that the sacrifices, possibly human, were made to appease the gods during the bad weather. On the basis of this archaeological evidence, the researchers concluded that the radiocarbon date of the eruption — 950 B.C. ± 150 years — should be refined to a date of 1100 B.C. with an uncertainity of +80 years and −60 years, which is more in tune with the ice core data.

Pang and Chou now are planning to search the Chinese literature for passages related to another large ancient volcano — the eruption of Thera (Santorini) in Greece, which many believe caused the destruction of the Minoan civilization. Geological dating puts the eruption anywhere between 1700 and 1300 B.C.; the Chinese records may help researchers to home in on a more precise date as well as to verify and quantify the eruption.

The greatest challenge in using historical literature as a geological tool is in describing such older eruptions, says Pang. The Chinese records are continuous and most reliable in their coverage of events that happened after 871 B.C. In the very ancient historical accounts, however, the dates are seldom more precise than half a century and hence less accurate than the ice core measurements. In the future, therefore, Pang would like to turn the whole process around, using ice core information (which goes back to 3850 B.C.) to put absolute dates on the older records, especially those kept by the three earliest dynasties, the Xia, the Shang and the Zhou.

Still, much useful geological information remains buried in the Chinese literature. Even for the last two dynasties, the Ming and Ching, the papers of the cabinet ministers — which alone occupy a quarter of a million volumes — have yet to be sorted out, says Pang. And adding to the mass of tomes already archived are some new volumes. According to Pang, a few very ancient books thought to have been lost were recently excavated from the Han tomb. In addition, the complete 2,500-year chronicle of the family of Confucius has just been opened to scholars. Pang also notes that the Chinese are about to print the first of two volumes of excerpts from the astronomy bureaus of 25 dynasties as well as reports from provincial and local regions. The excerpts were compiled by hundreds of volunteers scanning 150,000 volumes over the last 10 years and contain more than a million words pertaining to astronomy and meteorology.

So the final chapter on the study of geology through ancestral writings is far from complete. □