VOLCANIC DESTRUCTION

in the Book of Mormon: Possible Evidence from Ice Cores

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Eruption of Mt. Pinatubo, Philippines, 1991

The eighth chapter of 3 Nephi preserves one of the best accounts from antiquity of a natural disaster. It documents the destruction of entire cities and the deaths of, in all likelihood, tens of thousands of people during a terrible storm and accompanying earthquakes. The effects of the storm, including extremely high winds and intense lightning (see 3 Nephi 8:5–7, 12, 16), would have devastated crops and people. Recovery from such events would most likely have taken months, if not years. One of the most commonly asked questions concerns the cause of the storm. Because of its nature as described in the report, in conjunction with the movement of large amounts of earth that buried whole cities (see 3 Nephi 8:10), a number of studies have concluded that the storm resulted from volcanic activity.[1] If that is so—and I think that the evidence for this view is strong—then it may be possible to also find evidence in ice cores that scientists have begun to collect and study during the last half century.

Fallout materials from major volcanic eruptions, in the form of ash or sulfuric acid particles, are often trapped in the ice sheets covering Greenland and Antarctica. My purpose in this study is to address whether or not there is evidence in the ice cores collected in those areas for a large volcanic eruption at the time of Christ's death. Was there an eruption in the time period roughly around A.D. 30–40? (Attempts to precisely date the death of Jesus raise questions beyond the scope of this study.) The answer, based on published studies of ice-core research, is a tentative yes.

Background

Dr. Bart J. Kowallis gives the most extensive treatment of the subject in a *BYU Studies* article, published in 1998,[2] in which he makes a point-by-point comparison of the descriptions given in 3 Nephi with documented accounts of historical eruptions. He discusses how such things as thunder and lightning (3 Nephi 8:6–7, 12, 17, 19), whirlwinds (v. 12), quaking of the earth (v. 12), rending of rocks (v. 18), and a vapor of darkness (vv. 20–21) are all possible during a single eruption. Kowallis admits that such destruction would have been mostly local in nature. But considering the likelihood that "the area over which the Book of Mormon peoples roamed was . . . only a few hundred miles long and wide,"[3] the idea of a volcanic eruption being the source of the destruction is an entirely plausible explanation.[4] The *Journal of Book of Mormon Studies* recently cited more evidence that strengthens Kowallis's comparisons.[5]

Fig. 1. Map of Mesoamerica and Central America with triangles representing the known active volcano centers. (Map by Andrew D. Livingston)

If a volcanic eruption was the cause of such destruction, then there may be some geologic evidence of such an event. Kowallis notes that it was suggested in a FARMS lecture given by Marlon Nance on October 25, 1996, that it should be possible to geochemically characterize and date ash layers from sediment cores collected from the seafloor around Mesoamerica. This might make it feasible to identify ash from the possible eruption in question.[6] In addition, there should be deposits covering the landscape around the source volcano. The difficulty is that most of Mesoamerica[7] is dominated by volcanic deposits (see fig. 1). After Indonesia, it is the second most volcanically active region on the earth.[8] My dissertation research in Mesoamerica, although involving the correlation of much older volcanic deposits, has allowed me to see firsthand just how difficult it would be to find a particular deposit left from a single eruption during a specific year. Without any kind of local historical record of such an eruption, it would be far more difficult than trying to locate the proverbial needle in a haystack (the needle at least has different characteristics than the hay does). It would be more like identifying an individual cornfield in Nebraska.

There is another possibility, however, for direct evidence of a volcanic eruption during the time period in question. It was suggested in a recent issue of the *Journal of Book of Mormon Studies* that the evidence for an eruption might be found in glacial ice-core records.[9] I undertook the task of searching for such evidence from the extant literature. This is not the first time that the ice-core records have been applied to naturally occurring events in human history. Ice-core research has already been used to help confirm the climatic changes that forced the Vikings to abandon their colonies in Greenland and the New World, the unusual atmospheric phenomena at the time of Julius Caesar's murder, and the volcanic eruption that may have brought on the end of the Minoan civilization.[10] Ice-core records have even been correlated to known volcanic eruptions in Mesoamerica. A good example is that of the Ilopango volcano in El Salvador.[11] This was an eruption that some archaeologists believe helped spread the Maya Proto-Classic civilization throughout Mesoamerica, due to the migration of large numbers of people out of the disaster area.[12] Additionally, Richardson B. Gill, in his book *The Great Maya Droughts,* cites very strong evidence for the influence of volcanoes on the Maya civilization.[13]

Glacial Ice-Core Records

Almost all of the research done to date involving ice cores[14] has focused on global environmental change.[15] The ice cores from Greenland and

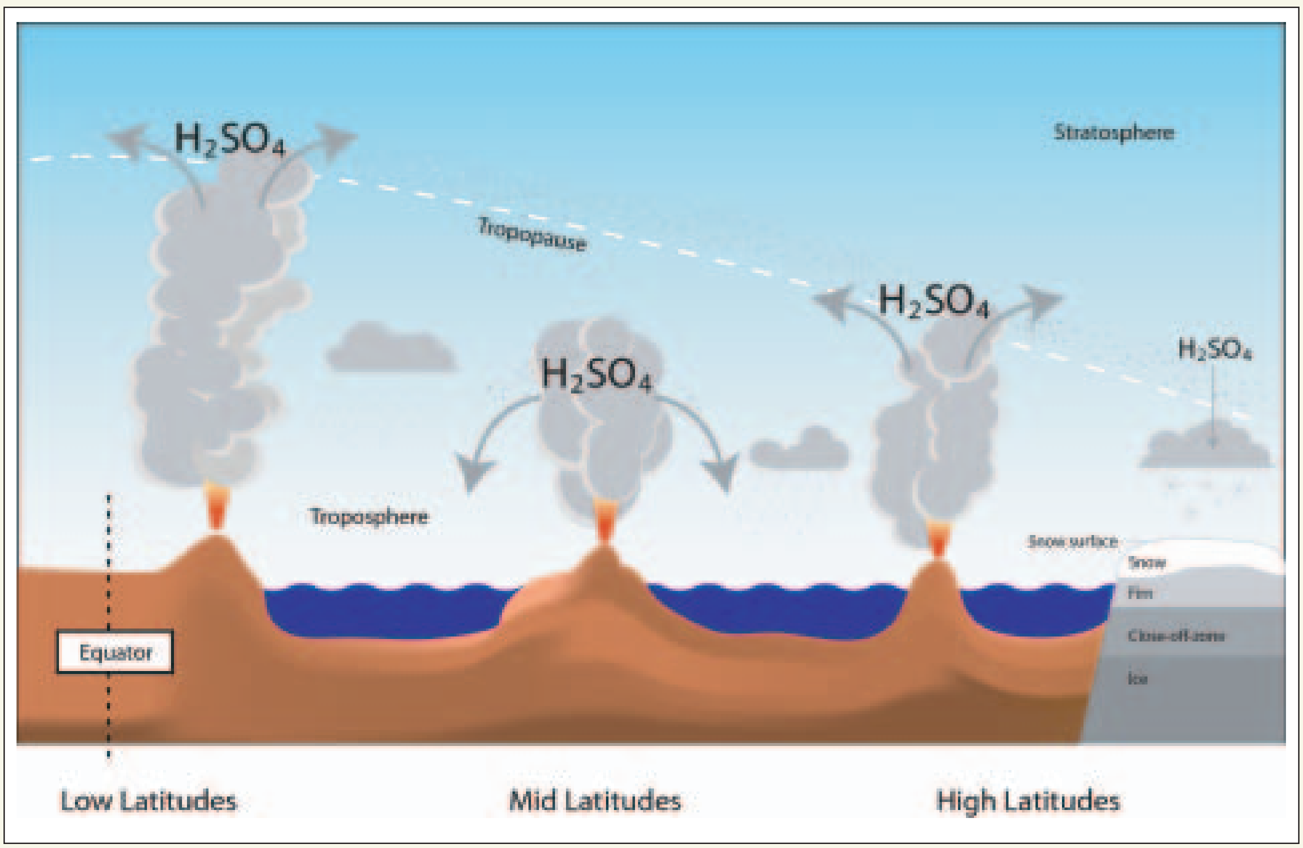

Fig. 2. During a volcanic eruption, ash and gases are injected into the atmosphere, where they buoyantly rise. The larger the eruption, the higher this material is carried. Once in the atmosphere, the ash and gases are transported by winds all around the world, including the poles. Eventually these aerosols (such as sulfuric acid aerosol, H_2SO_4) fall out of the atmosphere and are trapped in the polar ice and snow, forming a layer that records the eruption. (Illustration by Andrew D. Livingston)

Antarctica are important in the study of climate change because they serve as records of changes in the earth's atmosphere. This is because various gases and/or aerosols, along with other particles, became trapped within the ice as they were deposited with the original snow (see fig. 2). In this process, over time the snow becomes *firn,* a dense but porous form of ice that increases in density gradationally from the top to the bottom. Once the firn is buried to a certain point, it becomes compacted enough to form solid ice. Within this ice are trapped air bubbles that contain samples of the gases and/or aerosols that fell with the snow.[16] In the coldest areas of a glacier or ice sheet, these air bubbles remain undisturbed; and it is thought that, except for the decay of radioactive element impurities and some extremely slow diffusion across ice crystal boundaries, no chemical reactions take place. Each year another layer is added, and over time a record of the earth's atmospheric history is formed.[17] Core samples are drilled from this compacted snow and ice (see fig. 3). Individual years can be identified because the concentrations of various impurities that were deposited, like dust and nitrate, vary noticeably between summer and winter.[18] Often the annual layers can be clearly seen (see fig. 4).

This is important in the study of active volcanoes because, in addition to extruding the obvious materials like rock and ash, violent volcanic eruptions inject large amounts of various gases into the atmosphere (see fig. 9). This is done in two ways. The first consists of ash and gases carried by columns of superheated air that convectively rise directly from the vent of the volcano. The second is by ash clouds that rise, also due to convection, from pyroclastic flows, consisting of superheated rock, ash, and gas as they rush down the sides of a volcano during an eruption.[19] The most important of these gases are hydrogen sulfide and sulfur dioxide, which oxidize and combine with water in the atmosphere to produce sulfuric acid aerosol[20]—otherwise known as acid rain. Sulfate in the atmosphere tends to block incoming sunlight. Large eruptions that propel material as high as the stratosphere can affect the climate for years.[21] The effects are mostly the cooling of land and ocean temperatures due to the blocking of incoming solar radiation.[22] Even in the troposphere, where most of the earth's weather occurs and where the volcanic gases are quickly washed out, climatic effects can be felt. This is because the sulfuric acid at these lower altitudes acts as condensation nuclei for clouds. The clouds, in turn, can cool the earth's surface by reflecting incoming sunlight or warm it by trapping heat radiating from the ground.[23] If the eruption is large enough—and this is the key point for this study—some of these released gases, along with the aerosols they form, may be suspended long enough to become stored in glacial ice. Researchers use the evidence for volcanic eruptions that they find in ice cores in order to model small-scale climate changes.

The flip side of looking at the influence of volcanoes on the environment is that the history of global volcanism can be inferred from environmental evidence in the ice cores, such as the sulfuric acid contents of the various ice layers. This makes it possible to recreate earth's volcanic history without written records—at least in regard to a broad chronology.[24] Once this history is known, it may be possible to identify an individual eruption during a specific time period.

Fig. 3. Two drillers preparing to cut a new section of core in Antarctica. The person on the left is getting ready to attach the inner, rotating part of the drill to the outer, nonrotating shell, which is hanging from the drill cable. The driller on the right is using a tape measure to determine the depth of the hole. (Photo courtesy of Cara M. Sucher)

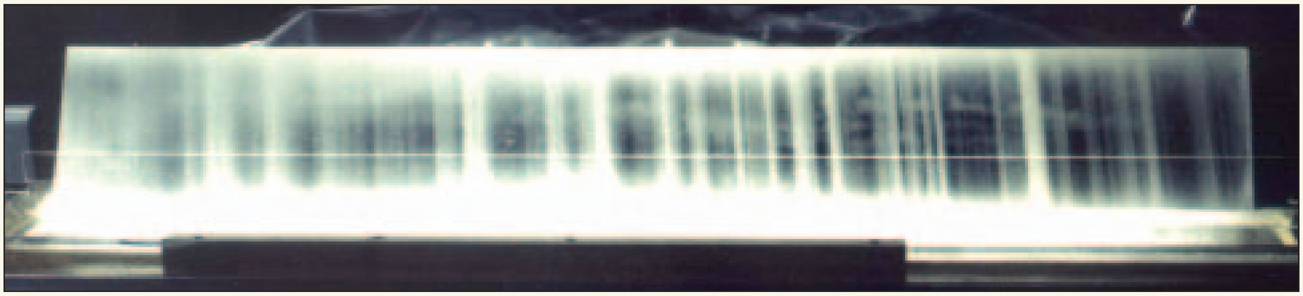

Fig. 4. A section of an ice core from the Greenland Ice Sheet Project 2. This is a section from deep within the ice sheet. Annual accumulation layers are clearly visible. (Photo courtesy of Cara M. Sucher)

Core Methodology

Volcanic gases are detected in the ice by measuring the acidity of the ice. The acidity is based on the concentrations of nitric acid, sulfuric acid, hydrochloric acid, and hydrofluoric acid. The acidity is most often measured using electrical conductivity.[25] Once a large increase in acidity is found in a layer, that layer is tested to determine the concentrations of the above acids. If a large amount of sulfuric acid is found, that is generally accepted as evidence of a volcanic eruption.

Ambiguities

Unfortunately, the ice-core record is not always clear. Whether or not evidence of a volcanic eruption is recognized in it is determined by a number of factors. Most of these are caused by natural processes, while others have to do with sampling and interpretation. For instance, the amount of sulfur released into the atmosphere does not always represent the size of an explosive eruption.[26] An example is the 1793 Laki eruption in Iceland, which produced huge amounts of sulfur dioxide but was not significantly explosive.[27]

One of the most important factors is the height in the atmosphere reached by any erupted material—thus the size of the eruption is critical. This is because gases that remain in the troposphere and do not reach the stratosphere tend to be washed out rather quickly, preventing widespread deposition of the erupted ash and aerosols.[28]

Even if material makes it to the stratosphere, material erupted at low latitudes near the equator may be hard to detect. Over the last 150 years there has been an average of 20 volcanic eruptions per year.[29] Most of these are too small to reach the stratosphere, but all of these eruptions together can still contribute to a volcanic "background signal" in the ice cores (see fig. 7).[30] In other words, at any given time—even as you read this—there is a lot of volcanic material dispersed in the atmosphere. Because there are so many active volcanoes in the high northern latitudes (Alaska, Japan, Iceland, and Russia), there is an extremely high background signal from them. This makes it difficult to distinguish minor events in the high latitudes from major events in the low latitudes, including Mesoamerica. The evidence from a large eruption in the tropics might be too diffused by the time it reaches the higher latitudes, where the ice traps it, to show up against the volcanic background signal created by a number of much smaller eruptions in those latitudes.

In the Southern Hemisphere there is another problem. Although it has its own explosive volcanoes, which would create the same sort of problem as found in Greenland, Antarctica as a whole lies at a greater distance from explosive volcanic sources, which are mostly in the Northern Hemisphere, and thus does not receive as much volcanic material. The southern continent also has very low precipitation rates. This low precipitation makes it difficult to reliably date the layers in the cores, because ash and aerosols might not be deposited at all.[31]

Another factor is that the tropopause, the boundary between the troposphere and the stratosphere, is at a higher altitude in the low latitudes than it is in the high latitudes. This makes it more difficult to get material into the stratosphere, where it could be dispersed to the poles (see fig. 2).[32] Local and regional weather conditions also have an effect. The dispersal direction of an eruption cloud can even vary depending on the season.[33] As mentioned above, it is possible that no precipitation takes place when the volcanic gases are transported over, say, Greenland. Thus the aerosols will remain in the atmosphere and be deposited someplace else.[34] Even after deposition, the sulfate-enriched snow may be scoured away by wind before the next precipitation event. Global wind regimes and air temperature, of course, play roles as well. When El Chichón, a volcano in southern Mexico, erupted in 1982, the wind patterns were such that the eruption cloud stayed within the tropics for six months—longer than was expected.[35] Warmer temperatures lead to melting, and melting tends to increase the nitrate concentration and thus nitric acid, which obscures the sulfate and sulfuric acid signal.[36] Melting also tends to muddle the core chronology.[37]

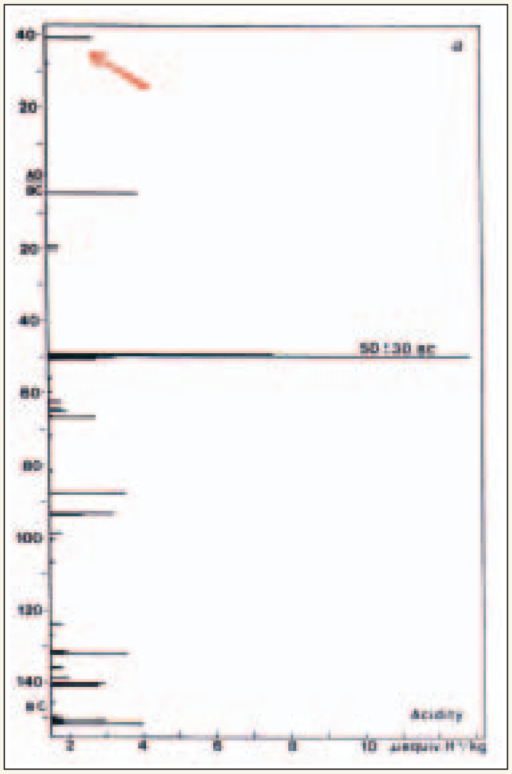

Fig. 5. "Unambiguous" volcanic signals from the Camp Century ice core in Greenland. The red arrow indicates the A.D. 38 signal. (Reproduced from Claus U. Hammer et al., 1980; see note 52 herein)

The perfect example of the complex factors that influence whether or not an eruption is detectable comes from the Mt. Pinatubo volcanic eruption in the Philippines in June 1991. Although located near the equator in the Northern Hemisphere, it has yet to be detected in Northern Hemisphere ice cores,[38] even though it has been recognized in Antarctic ice cores.[39] No one knows why this is the case.

There is also the fact that there are still only a limited number of ice cores, which limits the ability to correlate individual events between different cores. This increases the possibility for error in assigning known events to records in an individual core.[40]

Finally, researchers tend to ignore any acid signal that seems to be from an eruption with a Volcanic Explosivity Index (VEI) number less than 4.[41] Just as earthquakes are measured using the Richter scale, volcanic eruptions are measured using the VEI. Both represent magnitude. The VEI is based on a scale from 0 to 8[42] and measures the volume of material erupted.[43] It is thought that any eruption with a magnitude less than 4 will most likely not reach the stratosphere. But unless it is a known historic eruption, deciding what magnitude a concentration of sulfuric acid represents is filled with ambiguity. It is entirely possible for a distant, large (greater than 4), explosive eruption to leave only a small acidic "spike" in the ice, while a small (less than 3), nearby eruption could leave a large one. Eruptions with a magnitude of 3 tend to get overlooked, even though, according to the VEI, an eruption of magnitude 3 is considered "severe, violent, terrific" and can be of a duration of one to six hours.[44] This is important because an event large enough to generate the three-hour time period set in 3 Nephi might have a VEI magnitude of a 3 and thus not be reported in the modern literature, even if it is evident in the ice-core record.

Ice-Core Dating

Unless researchers are interested in a specific interval in time, most do not sample every layer of the cores, which makes it possible to miss the peaks of some events. So any record must be seen as minimalist—there were many more eruptions than are indicated in the research literature.[45] Also, any date of a layer in the ice will be two to three years later than the eruption due to the travel time required for the material to reach Greenland or Antarctica from the volcanic source.[46] This point, too, is important for this paper's purpose.

The oldest accepted written record of an eruption is the A.D. 79 Vesuvius eruption that destroyed Pompeii.[47] Geologically, other eruptions are known, but the lack of historical records makes it very difficult to identify specific eruptions as sources for individual acid peaks. Many signals that appear in the ice cores, even during the last 200 years, are from unknown sources.[48] Dating tends to be fairly good because it is almost like counting tree rings, although, due to some of the ambiguities mentioned earlier, it is not quite that simple. The margin of error in dating is determined in two ways. The first is to compare two cores from different locations that cover the same time period and attempt to line up large acid concentration spikes between them. The second is simply to count layers and attribute large spikes to known events. In the words of Gregory Zielinski, a prominent ice-core researcher:

> Dating error [in Greenland] is now thought to be 1% for the last 30,000 years of record. . . . Time lines for established volcanic events as derived from both the chemical signal . . . and the presence of tephra [volcanic glass] from known historical eruptions were used to verify the counting [of ice-core layers] and to correlate with other ice cores from Greenland. Because the original layer counting came to within 10 years of the signal *thought* to be related to the A.D. 79 Vesuvius eruption, the cumulative dating error may only be about 0.5% for the last 2100 years.[49]

Thus, at least in this case, the error for dating an eruption like Vesuvius that occurred within the same general time period as the possible Book of Mormon event is about 10 years.

Having a knowledge of a known eruption can color the interpretation of the ice-core record as well. In doing research, sometimes we see what we are looking for, not because it is really there, but because it fits our expectations. Part of the dating of the core relies on matching the spikes or peaks with documented eruptions and thus establishing the date for a given layer by inferring that it represents an eruption of a certain date. Although this is probably fairly reliable, it does leave the door open for some ambiguity. What if a documented eruption does not leave an ice-core record, but an undocumented one occurring the same year as the documented one does? In other words, any acidic spike in the ice-core record around A.D. 79 is considered to be a record of Vesuvius even if it isn't. In all fairness, there is no way of knowing otherwise without some other record. However, this could be a problem for the possible Book of Mormon event because at least two eruptions with a VEI of at least 3 are thought to have taken place during the same relative time period as the events in 3 Nephi. These were in A.D. 19 and A.D. 46. Both occurred at the island of Santorini in the Mediterranean.[50]

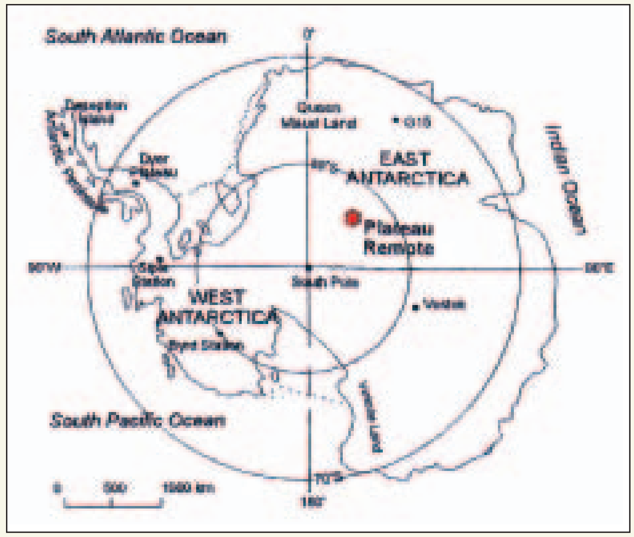

Fig. 6. The red star shows the location of the Plateau Remote ice core. (Reproduced from Jihong Cole-Dai et al., 2000; see note 30 herein)

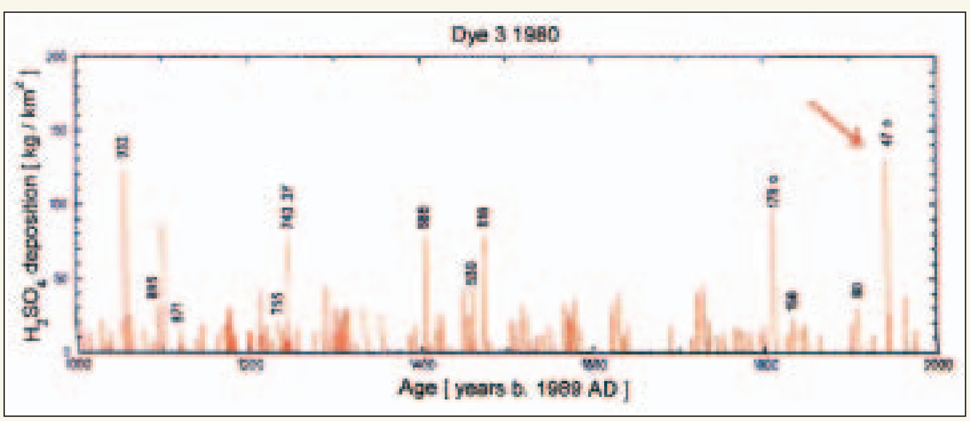

Fig. 7. Acidic spike in the Dye 3 ice core at A.D. 47, indicated by the red arrow. (Reproduced from Henrik B. Clausen et al., 1997; see note 25 herein)

The Evidence

So where does all of this bring us? Is there any evidence from ice cores of a volcanic eruption around the time of Christ's death? The short answer is yes, but it is far from conclusive. It does, however, add some strength to the arguments for a volcanic origin for the destruction narrated in 3 Nephi.[51]

The strongest evidence comes from a core known as the Camp

Fig. 8. Locations of ice cores from Greenland. (Drawn after Richard B. Alley, 2000; see note 14 herein)

Century ice core, collected in northwest Greenland (see fig. 8). A continuous measurement of the core's acidity profile was made extending from a depth in the ice of 558 meters to the bedrock beneath the ice. This profile corresponds to a time span from A.D. 43 to 100,000 B.C. The authors illustrate, in chart form, all of the "unambiguous volcanic signals" with VEI ratings of 3 or greater for the time period spanning 150 B.C. to A.D. 43. There is clearly a signal at approximately A.D. 37 or 38 (see fig. 5). However, the potential error is plus or minus 30 to 40 years. The authors do not discuss the signal because it is minor compared to some of the others that they are clearly more interested in.[52]

In two other sets of cores from Greenland—the Greenland Ice Core Project (GRIP) ice cores and the Dye 3 ice cores—volcanic signals were detected during the same time period. The Dye 3 ice core shows a distinct acid spike at A.D. 47 (see fig. 7). Unfortunately, the acid is predominantly nitric acid, which is not related to volcanism and is most likely, as discussed by the researchers, a result of warm air temperatures and melting. The sulfate component of this spike is still twice the amount of the background, which does indicate volcanism, but the signal is too diluted by the nitric acid to be completely unambiguous. However, the possibility of a volcanic source contributing to the A.D. 47 spike from the Dye 3 core is strengthened by a core drilled at Plateau Remote in

Fig. 9. San Cristóbal volcano in Nicaragua. This is an example of one of the many active volcanoes in Mesoamerica. Note the steam and gases venting from the volcano.

east Antarctica (see fig. 6). This core contains a clear volcanic signal at A.D. 46. It has a dating error of "a few years"—but the authors give no further specifics.[53] There are other small but strong acidic spikes between A.D. 1 and A.D. 47 within the Dye 3 core, but the authors do not discuss them in the article.

In the GRIP ice core, there is a spike around A.D. 1, but it is not discussed either. There are no others before that of A.D. 80, which the authors relate to the eruption of Vesuvius. The GRIP core is thought to be a better record of pure volcanic eruptions because it does not appear to have been subject to melting. However, its location at a higher altitude (3238 m) and latitude (72.58º N) may also have resulted in its not recording some events that were recorded in the Dye 3 core, which is from a lower altitude (2480 m) and latitude (65.18º N). Certain layers in the Dye 3 core are clearly volcanic, based on their sulfate content, but do not appear in the GRIP cores—for instance, a large event in the Dye 3 at A.D. 178. This event, however, is not discussed by the authors. They state that there is an error of plus or minus two years at the A.D. 934 level in the GRIP core, but at the 1084 B.C. level, in both the GRIP and Dye 3 cores, that error is plus or minus 10 years.[54]

There is nothing in any of the records to indicate what or where the sources of the eruptions might have been. However, recent evidence has been discovered of an eruption at Tacaná volcano on the border of Mexico and Guatemala. This event is dated between A.D. 25 and A.D. 72 and correlates with an interruption of construction at the city of Izapa. The eruption was followed by mudflows that inundated parts of Izapa.[55] This eruption was moderate in size—similar to that of Soufrière Hills, Montserrat, in the early 1990s—and unlikely to have been the sole cause of the destruction described in 3 Nephi. Determining whether or not this eruption caused or contributed to that destruction at all requires additional research.

Conclusion

My purpose in this paper was to lay out the ice-core evidence for a volcanic eruption around the time of Christ's death that might be correlated with the destruction discussed in 3 Nephi. There is evidence for large eruptions, within the margin of error, for the period of A.D. 30 to 40. However, so far it is not possible to determine the exact geographic location of those eruptions. Despite this, the discovery of a volcanic eruption at Tacaná volcano during the period in question, combined with the ice-core record, seems to strengthen the argument for an eruption as part of the cause of destruction described in 3 Nephi. This evidence is not conclusive and leaves the door open for some criticism of the volcanic hypothesis, but it cannot be argued that there is no evidence outside the Book of Mormon for a volcanic eruption during that time period. The benefit from this study remains: there is evidence for volcanic eruptions during the time period described in 3 Nephi 8. In the end, it is up to the reader to decide how much this evidence strengthens the argument for a volcanic origin of the great destruction.