



ARCHAEOLOGY AND VOLCANISM

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GLOSSARY

archaeology The scientific study of the physical remains of ancient human cultures and the art of interpreting their significance.

Bronze Age Period of human cultural development in Europe and the Near East characterized by the use of bronze tools and weapons that began between 4000 and 3000 years ago and ended with the Iron Age (about 1200 B.C.).

etiology From a Greek term meaning cause, origin, or source; in the study of ancient myth, it refers to oral traditions that attempt to explain the origins of natural or social phenomena.

geomythology The study of ancient oral traditions that pre-

serve memories of prehistoric geologic events, such as earthquakes or volcanic eruptions.

lahar An Indonesian term for a debris flow or mudflow originating on a volcano.

Minoan culture An ancient civilization centered on Crete and characterized by the building of large palace complexes, such as that at Knossos; it dominated the Aegean region from about 2000 to 1450 B.C.

mudflow A water-saturated mass of rock debris that moves downslope as a liquid under the pull of gravity; it can travel many tens of miles beyond its source.

Neolithic The New Stone Age; in Europe and the Mediterranean basin, it refers to prehistoric cultures using stone implements and characterized by settled agrarian pursuits.

phreatic Refers to a steam eruption that produces no fresh magma. A common precursor of eruptive activity, it is caused when groundwater, heated by a magmatic source, flashes into steam.

Plinian eruption Named for Pliny the Younger, a violently explosive eruption that ejects a large volume of tephra high into the stratosphere.

pyroclastic A Greek term meaning fire-broken; it refers to fragmental rock ejected during an eruption.

pyroclastic flow A dense, hot, dry mixture of gas and incandescent rock fragments that travels rapidly along the ground surface, typically at speeds of hundreds of feet per second.

pyroclastic surge A turbulent cloud of gas and fine rock

particles that flows over and above the ground surface at extremely high velocities. More dilute than pyroclastic flows, surges are not topographically constrained but sweep over ridges, hills, and other topographic obstacles.

tephra Rock fragments blown into the air above an erupting volcano; tephra ranges in size from fine ash to blocks many tens of feet in diameter.

DESPITE THEIR REPUTATION as agents of destruction, explosive volcanoes have provided a major aid to archaeologists' study of ancient human remains. Large-volume eruptions of tephra can not only quickly and thoroughly bury entire settlements and other artifacts, effectively sealing them for posterity, but also typically lay down widespread layers of ash that, when dated, serve as valuable time markers. When the date of an extensive tephra layer is known, it enables researchers to establish the relative ages of objects found within, above, or below the deposit.

I. VOLCANOES AS PRESERVERS OF ARCHAEOLOGICAL SITES

A. The Science of Archaeology and Its Relation to Volcanism

Almost from its inception, archaeology has been intimately associated with volcanism. In many important ways, archaeology evolved as a scientific discipline in the laboratory provided by Herculaneum and Pompeii, Roman cities located on Italy's Bay of Naples that were buried in A.D. 79 by a catastrophic eruption of Mount Vesuvius. Rediscovered in the early 18th century, the two sites were first viewed as mere repositories of artistic plunder to furnish the private estates of European collectors. By the mid-19th century, however, under the leadership of such pioneering archaeologists as Giuseppe Fiorelli, excavators at Pompeii eventually established the systematic criteria for uncovering, cataloging, and conserving antiquities that characterize archaeology today.

An interdisciplinary science that utilizes the contributions of anthropology, geology, paleontology, ethnology, chemistry, and physics, modern archaeology involves studying and interpreting the material remains of ancient human cultures. Its objectives combine scientific and humanistic goals, including the identification and

analysis of artifacts to illuminate the long-forgotten cultural processes that created them. As a multidisciplinary enterprise, archaeology includes attempts to reconstruct the full spectrum of elements composing a vanished society, including such components as its economy, commerce, political organization, religious beliefs, and mythology.

Paradoxically, volcanoes, which are popularly regarded as mere destroyers, are perhaps nature's most effective preservers of ancient human structures and settlements. No other natural phenomenon can so quickly and thoroughly bury large areas, including evidence of human occupation, protecting artifacts from subsequent damage. Exposed sites gradually covered by slower geologic processes, such as sporadic flooding or sedimentation, are typically subject to severe erosion and destructive human activities, including war, vandalism, and the deliberate demolition of older edifices. By contrast, towns such as Pompeii, Herculaneum, and Akrotiri, a Bronze Age settlement on the island of Thera (Santorini), were rapidly engulfed in pyroclastic ejecta and survive relatively intact. Besides being spared the depredations inescapable in surface exposure, the buildings, artwork, and other artifacts buried by voluminous tephra falls or pyroclastic flows remain in their original context, their spatial and functional relationships largely undisturbed.

Volcanism's agency in preserving the human record extends to the earliest stages of human evolution. About 3.5 million years ago, at Laetoli in Tanzania, an adult hominid and one or two smaller companions, perhaps a female and/or child, walked upright across a newly deposited layer of ash. After a brief rainstorm splattered across the area, a second ash eruption covered the hominid footprints, effectively sealing one of the oldest surviving evidence of bipedalism until its discovery by 20th century investigators.

II. HERCULANEUM AND POMPEII: CITIES OF THE EARLY ROMAN EMPIRE

A. Historical Significance

Pompeii, in A.D. 79 a thriving commercial center of about 20,000 inhabitants, and Herculaneum (Figs. 1 and 2) a largely residential town of about 5000, are uniquely important. Frozen in time, they offer a superbly detailed picture of life in the early Roman Empire, encompassing



FIGURE 1 Whereas most buildings in Pompeii are roofless, crushed by the accumulation of tephra from Vesuvius, many of Herculaneum's structures, such as these small shops, retain their upper stories. An affluent resort town on the Bay of Naples, Herculaneum is perhaps the best-preserved urban site of the early Roman Empire. (Photo courtesy of Dr. James Straukamp.)

temples, theaters, shops, private houses, gardens, fountains, public baths, swimming pools, and a miraculously preserved library. Interred so swiftly that most residents had no time to save their possessions, the ruins contained a rich variety of rare items, including gold jewelry, silver dishes, the most complete known set of Roman surgical

instruments, and even wax tablets inscribed with bank records. Recovery of Greco-Roman statuary, paintings, and furniture influenced 18th and early 19th century art and architecture throughout Europe and America, where Thomas Jefferson modeled Monticello on classical styles.



FIGURE 2 Engulfed by pyroclastic flows during the A.D. 79 eruption of Mount Vesuvius, the Roman town of Herculaneum has been only partially excavated. Property owners of the modern town of Resina, built atop the site, effectively prevent further excavation. (Photo courtesy of Dr. James Straukamp.)

B. Recent Discoveries at Herculaneum

Besides their historical role as a testing ground for new archaeological techniques and concepts of preservation, Pompeii and Herculaneum continue to yield invaluable information about the Roman world, including the physical attributes of the cities' former inhabitants. Until the early 1980s, when about 130 largely intact skeletons were exhumed along Herculaneum's former waterfront, it was assumed that most of Herculaneum's population had managed to escape the city alive. The discovery of so many well-preserved remains is particularly important because the Romans, who typically cremated their dead, otherwise have left little evidence of their bodily characteristics. Caught in the fierce heat and swirling ash of a pyroclastic surge, the victims had apparently been asphyxiated while attempting to flee by boat. (An overturned 30-foot wooden vessel was found nearby.) The skeletal remains at Herculaneum are considered invaluable because they encompass individuals of all ages and classes, ranging from a bejeweled Roman matron to a teenaged slave girl to a middle-aged soldier, sword in hand, whom the surge had thrown to the ground face-down. Hundreds more skeletons may still await discovery.

C. Sequence of Eruptive Events in A.D. 79

The effects of Vesuvius's outburst on the nearby human population are now better understood than those of any other ancient volcanic disaster. Not only did a remarkably observant Roman nobleman, Pliny the Younger, write two letters to the historian Tacitus in which he carefully described Vesuvius's behavior, but modern volcanologists led by Haraldur Sigurdsson have been able to correlate Pliny's account with particular strata deposited by the eruption. The eruptive sequence, and its effects on the human population, is now well understood. After some preliminary activity, which dusted one slope of the volcano with a light tephra fall, the main eruption began about 1 P.M., August 24 with an explosive discharge of pumiceous ash, forming an ash column that, in Pliny's words, resembled a towering pine tree with spreading upper branches. For the next 11 hours, Vesuvius ejected a vertical eruption cloud (called Plinian after the Roman author who first described the phenomenon) that rose approximately 12 miles into the stratosphere. Carried south-southeastward by the prevailing winds, the ash canopy enshrouded Pompeii, extinguishing sunlight

and raining lapilli (the Latin term for small stones) over the city, where pumice accumulated at the rate of 6 inches per hour. Lying four miles upwind from Vesuvius, Herculaneum received only a trace of ash during this phase of the eruption.

Shortly after midnight, however, the character of the eruption abruptly changed. As Vesuvius tapped deeper levels of its magma chamber, the gas-rich volatile mixture that had sustained the Plinian cloud became increasingly depleted, causing the ash column to collapse. Expanding horizontally, the turbulent ash cloud separated into a fast-moving pyroclastic surge that swept through Herculaneum, killing all who remained there, and a somewhat slower-moving pyroclastic flow that enveloped the town, initiating its burial. As the eruption column continued to fluctuate, a second surge and pyroclastic flow were generated an hour later. A third, at 5:30 A.M. on August 25, finished the work of entombing Herculaneum under a hot ash deposit tens of feet thick.

The third pyroclastic flow, which had interred Herculaneum, was deflected from Pompeii by the city's massive walls. The fourth, however, exhibited lethal energy, racing 6 miles from Vesuvius's crater and blasting through the city like an incandescent sandstorm. Rushing across the 7-foot thickness of pumice that had previously fallen, the flow toppled exposed walls, sheared off roofs and upper stories of buildings, and asphyxiated the remaining inhabitants.

Trapped in the fourth pyroclastic flow, thousands of fleeing Pompeians were instantly entombed. When their bodies decayed, they left behind hollow spaces in the ash. Recognizing that these cavities were, in effect, molds of human figures, 19th century archaeologists filled them with liquid plaster, allowed it to solidify, and then removed the surrounding ash. The plaster casts thus formed are astonishingly lifelike, some showing in detail the agonized facial expressions of the volcano's victims.

In 1961, archaeologists unearthed a particularly poignant group in a location called the Fugitives Garden, where casts were made of seven adults and six children. Like many of the 57 people killed in the 1980 pyroclastic surge from Mount St. Helens, the fugitives appeared to have died of suffocation from inhaling the pervasive ash. Estimates of the fatalities in Pompeii—some archaeologists state that about 2000 perished—were based on the number of skeletons found in the lower pumice deposits and the body-shaped cavities formed in the upper pyroclastic flow deposits. With the realization that the pyroclastic surges and flows probably killed simultaneously many of the people who were

TABLE 1 Some Representative Archaeological Sites Related to Volcanism

<i>Site name and location</i>	<i>Volcano</i>	<i>Date</i>	<i>Significance</i>
Pompeii & Herculaneum, Italy	Vesuvius	79 A.D.	Entire Roman cities preserved
Akrotiri, on Santorini, Greece	Thera	late 17th century B.C.	Minoan-age city; rare murals
Catal Huyuk, central Turkey	Karapinar cinder cone field (?)	6200 B.C.	Earliest known painting of a volcanic eruption
Maya settlements, El Salvador, Central America	Ilopango	Third century A.D.	Massive disruption of Maya population centers
Northwest Costa Rica, Central America	Arenal	c. 1550 B.C. to A.D. 1080	Average of 4 eruptions per century fails to disrupt population
Arizona, U.S.A.	Sunset Crater	c. 1060 A.D.	Causes redistribution of native agricultural sites in vicinity
Washington State, U.S.A.	Rainier	c. 3600 B.C.	Mudflow buries campsite and tools
Washington State, U.S.A.	St. Helens	c. 1500 B.C.	Abandonment of native habitats in southwest Cascade Range
Yukon Territory, Canada	White River Volcano, Alaska	20 A.D. and 720 A.D.	Triggered mass migrations of Athapaskan peoples, northwestern Canada
Aleutian Islands, Alaska	Aleutian Range volcanoes	18th Century A.D.	Probable submarine activity and tsunamis displaces coastal Aleut tribes

fleeing along the roads outside Pompeii's city gates, historians now believe that many more thousands perished in the disaster.

At 8:30 A.M. on August 25, Pliny witnessed the generation of the sixth and largest pyroclastic surge, "a fearful black cloud . . . rent by forked and quivering bursts of flame" that swept across the Bay of Naples toward Misenum, located 20 miles west of Vesuvius. Fleeing the city with hordes of panicked refugees, Pliny noted that "many besought the aid of the gods, but still more imagined there were no gods left, and that the universe was plunged into eternal darkness for evermore."

D. Rediscovery and Excavation

Although some survivors later burrowed into the deposits covering Pompeii, retrieving valuable objects and even building materials, the buried cities eventually became almost entirely forgotten until 1709, when laborers digging a well happened upon Herculaneum's theater. Despite being rediscovered first, most of Herculaneum still lies underground, embedded in pyroclastic flow deposits that hardened to the consistency of cement. Besides the enormous difficulty of removing the solidified

ash enshrouding the site, landowners in the modern town of Resina, which sprawls atop the deposits covering Herculaneum, refuse to permit archaeologists to expand the excavations.

Beginning in 1738, excavators bored a network of tunnels through part of the town, haphazardly looting statuary and other portable art and carelessly wrecking any structure considered uninteresting. One of the most promising 18th century finds was an elaborate residence known as the Villa of the Papyri, which sheltered a library of 1800 carbonized scrolls. Hopes that this collection would yield literary masterpieces, such as a lost tragedy by Sophocles, were dashed when most of it turned out to be the work of a minor Epicurean philosopher, Philodemus. The villa's presumed owner, L. Calpurnius Piso, the father-in-law of Julius Caesar, was Philodemus's patron.

Today most of the 18th century tunnels burrowing through underground Herculaneum are closed, and visitors can no longer walk across the theater's ancient stage. Even though most of Pompeii has been opened to light and air, Herculaneum remains largely buried, its mysteries still hidden. The few buildings now exposed, such as the elaborate suburban baths, represent only a fraction of structures waiting to be discovered, along with an unknown number of sculptures, paintings, and scrolls.

III. AKROTIRI: AN AEGEAN BRONZE AGE CITY

A. Relation to Minoan Civilization

A particularly spectacular example of volcanic preservation occurs on the Aegean island of Thera (also called Santorini), about 60 miles north of Crete, where a late Bronze Age city, named for the nearby modern village of Akrotiri, was engulfed during a cataclysmic eruption of the Thera Volcano in the late 17th century B.C. Dubbed the Pompeii of the Aegean, Akrotiri was similarly buried by voluminous tephra falls and pyroclastic flows. By far the best preserved settlement of its era (corresponding to Late Minoan III-A on Crete), Akrotiri was a prosperous sea port, enriched by maritime trade with Crete and other parts of the eastern Mediterranean region. The luxury and opulence of its multistory dwellings (some rose three or even four stories high) is indicated by their technological sophistication (indoor running water and flush toilets) and artistic splendor (some of the most extensive and beautiful wall paintings to have survived from the ancient world).

Although the site of Akrotiri was continuously inhabited since the Neolithic period and hence represented a native Cycladic culture, pre-eruption Akrotiri was profoundly influenced by Minoan civilization. Named by modern archaeologists after Minos, a mythical king of Knossos on Crete, Minoan culture dominated the Aegean region between about 2000 and 1450 B.C. The Akrotiri wall paintings reveal a typically Minoan delight in physical nature and the human form. Most of the human figures, including richly dressed and bejeweled female figures and nude youths carrying fish, probably depict participation in religious processions or other rituals. Other paintings focus on portraying highly stylized flowering plants, soaring birds, or animals, both wild and domestic, including the famous blue monkeys adorning the aptly named House of the Frescoes. Perhaps most important for archaeologists are the lavish wall murals showing a Bronze Age naval fleet and urban waterfront scenes, one of which may represent Akrotiri and its people.

Because the artists made no attempt to keep the plaster they painted on wet and continued to paint over patches that had already dried, the frescoes are unevenly preserved. Generally intact where the paint had permeated wet plaster, the wall paintings quickly flake away from the dry areas, challenging the techniques of Greece's most skilled archaeologist-restorers. Even so, Akrotiri's frescoes survive in larger fragments than the

roughly contemporary murals from other Aegean sites, including Cretan Knossos. Besides their exceptional state of preservation, the paintings are unusual in that they generally remain in their original positions, allowing archaeologists to reconstruct the original decoration of entire rooms and to speculate on the probable relationship between scenes painted on different parts of the same room.

B. Architectural Sophistication

At the time of its destruction, Akrotiri was probably one of the Aegean's major ports, with a population of several thousand. Although only a small fraction of the town, which may have covered several tens of acres, has thus far been excavated, it appears that prehistoric Akrotiri closely resembled the general layout of modern villages on the island. Designed for a society functioning without vehicles, its streets were narrow, wide enough only for two loaded donkeys or other pack animals to pass one another. Some archaeologists suggest that the town's zigzag streets and small, irregularly shaped open spaces, such as the aptly named Triangle Square, may have been deliberately planned to block gusty winds and to prevent heavy rains from transforming thoroughfares into stream beds.

Judging from the small portion of the town now exposed—a mere ten houses have been exhumed and most of these have not been fully explored—it seems that the community was highly organized, with special attention given to sanitation. The streets, apparently well maintained, were generally paved with large, relatively flat stones; beneath this flagstone surface ran a carefully constructed sewage system consisting of stone-lined ditches covered with stone slabs. These underground sewers received effluents from neighboring houses via clay pipes incorporated in house walls. The closely packed, multistory domestic edifices and the entire absence of accommodations for livestock or other animals indicates that Akrotiri's inhabitants were thorough-going urbanites.

Individual houses were built of native stone and clay, the masonry walls strengthened against seismic hazards by both horizontal and vertical timber reinforcements. Although no standard house plan exists at Akrotiri, most builders observed some accepted conventions, including the placement of a window next to the main doorway, a practice that may account for the Greek word for "window" (*parathyron*, which literally means beside the door). The same passion for interior light and color that characterize the Minoan palace architects on Crete

appears in Akrotiri's private houses. Virtually every room contains a window, with relatively large ones punctuating upper storeys, and every house uncovered to date boasts vivid wall paintings. It is possible that the presently excavated dwellings represent the home of the town's more affluent residents, but the abundance of these distinctive amenities indicate that at least a significant part of the population enjoyed both a luxurious domestic environment and a strong aesthetic sense.

With some structures rising three stories or higher, staircases are common and are built of both stone and wood. Most stairways rested on piles of rubble enclosed in a solid wood framework set between parallel walls, with stone treads laid atop the rubble. Whereas families had their living quarters on the upper levels, the ground floor was typically devoted to storage of foodstuffs and other supplies. Most houses also had workshops equipped with such stone tools as hammers and anvils, as well as private mills, complete with grindstones and containers to catch the ground flour.

Although no wooden furniture or building materials have survived, the decay of these objects left cavities in the surrounding ash deposit, into which archaeologists poured liquid plaster, resulting in plaster molds of such household items as beds, tables, and even an elaborately carved three-legged stand that may have been used for religious purposes. Besides a plethora of decorated pottery and huge storage jars, some examples of beautifully crafted metalwork have also been found, ranging from bronze awls and daggers to large bronze cooking utensils.

C. The Thera Eruption

The scarcity of valuable jewelry or metal goods, as well as the total absence of human remains, indicates that Akrotiri's people had ample warning of the disaster that overtook their city. As at Pompeii, the combined efforts of volcanologists and archaeologists have enabled researchers to interpret the stratigraphic record, reconstructing the order of events that doomed Akrotiri. According to recent studies, precursory earthquakes severely damaged buildings throughout the town, perhaps years or even decades before the eruption occurred. The city's high degree of social organization is suggested by major communal program following the temblor to clear debris from the streets, tear down ruined buildings, and repair weakened structures. Extensive reconstruction was still underway when further seismic activity apparently prompted the inhabitants to abandon Akrotiri permanently, taking with them their most valuable possessions. The volcano's interruption of this restora-

tion process is effectively symbolized by the presence of two vessels of dried plaster and a third containing dried paint in a second-story bedroom of the West House, where painters were busily redecorating until forced to lay aside their work.

The climactic eruptive sequence began with phreatic blasts that produced a thin layer of ash, followed by a paroxysmal outburst that ejected between 5 and 7.5 cubic miles of magma, creating approximately 12.5 to 19 cubic miles of pyroclastic material. It was previously assumed that this Plinian event triggered the collapse of Thera's former summit, creating the large caldera, subsequently flooded 1000 feet deep by the invading sea, that occupies most of the island today. Geologists have recently concluded, however, that a caldera already existed on Thera at the time of the "Minoan" eruption, although it was probably enlarged by further subsidence of the volcanic edifice. The island's present crescent shape, deriving from a prehistoric collapse long before the Minoan era, inspired its ancient name *Stronghyle*, which means round.

The Thera catastrophe is notable for reputedly spawning two celebrated theories—one ancient and one modern—about the sudden disappearance of a technologically advanced prehistoric civilization. According to one hypothesis, the eruption that buried Akrotiri and other prosperous towns on Thera was the inspiration for Plato's famous myth of Atlantis. In his dialogues, the *Critias* and *Timaeus*, Plato has the Athenian statesman Solon relate a tale he heard from Egyptian priests in the sixth century B.C. concerning a tyrannical island kingdom, supposedly located beyond the Pillars of Hercules (the Straits of Gibraltar), that disappeared in a sudden catastrophe. The Atlantis tradition, in this view, was based on the classical Greeks' dim memories of the disaster that overtook Thera and other Minoan sites. Plato's locating the vanished civilization out in the Atlantic was merely an imaginative but inaccurate attempt to place the ancient culture beyond the realm of the known world.

D. Thera and the Decline of Minoan Political Dominance

A second, contemporary theory links Thera's outburst with the demise of Minoan civilization. In 1939, the Greek archaeologist Spyridon Marinatos suggested that the Thera event was powerful enough to change the course of Mediterranean history, weakening Minoan political dominance of the Aegean and permitting the warlike Mycenaeans of the Greek mainland to invade and

conquer Crete. Tsunamis generated by Thera's collapse, Marinatos suggested, may have overwhelmed Minoan ports, demolishing any fleets harbored there and decimating their maritime empire. Recently revised dating of the Thera eruption, placing it about 1645 B.C. (according to ice core samples) or 1628 B.C. (from tree-ring evidence), however, makes it unlikely to have triggered the final decline of Minoan power, which did not occur until about 1450 B.C. In the absence of a substantial ash layer on Crete or unequivocal evidence of flood damage to its ports, most historians now conclude that Thera's explosions were not responsible for the eclipse of Minoan hegemony in the Aegean. Efforts to connect the eruption with the biblical plagues on Egypt, described in the Book of Exodus, or with the Israelites' miraculous deliverance at the Red Sea, when a pursuing Egyptian army was allegedly overwhelmed by a "wall of water" and drowned, are equally unsubstantiated. The exodus from Egypt, which most scholars place in the 13th century B.C., occurred almost four centuries after the Thera disaster.

IV. CATAL HUYUK: THE EARLIEST REPRESENTATION OF A VOLCANIC ERUPTION

Although archaeologists have not yet discovered a fresco depicting the Thera volcano, the ruins of Catal Huyuk in central Anatolia (modern Turkey) contain a remarkable Neolithic portrayal of an active volcano, the earliest known visual record of a volcanic eruption. Dating to

about 6200 B.C., the Catal Huyuk mural (Fig. 3) shows a cinder cone, looming steeply above a town nestled at its base, ejecting tephra from the summit vent. More than six millennia older than the fresco at Pompeii that portrays Bacchus (the Roman wine god) presiding over vineyards near Vesuvius, this painting bears witness that human interest in documenting volcanic phenomena began at an extremely early date.

V. MESOAMERICAN ARCHAEOLOGICAL SITES

A. Probable Effects of the Ilopango Eruption on Maya Cultural Development

Volcanic activity has also preserved a number of important archaeological sites in the New World. During the third century A.D., a caldera-forming eruption of the Volcan Ilopango devastated the highlands of El Salvador, Central America, covering a broad area under pyroclastic flows and a much larger region under thick layers of tephra. Whereas land lying within a radius of about 60 miles of the vent was rendered completely uninhabitable, areas lying farther away suffered varying degrees of environmental damage, leaving a large population of survivors with no means of subsistence. Recent studies by Payson Sheets and others suggest that the eruption, occurring at the close of the Proto-classic Maya period (A.D. 200–300), had unusually long-term social and economic effects on the evolution



FIGURE 3 Dating from about 6200 B.C., this wall painting from a shrine at Catal Huyuk (central Anatolia, Turkey) is the oldest extant picture of an active volcano, perhaps one of the cinder cones in the Karapinar volcanic field that lies about 30 miles east of Catal Huyuk. Although the volcano is shown exhibiting only mild Strombolian activity, the artist's placement of a Neolithic town in such close proximity to its base suggests some anxiety about its eruptive behavior. (Courtesy of James Mellaart, *Catal Huyuk: A Neolithic Town in Anatolia*, 1967, McGraw-Hill.)

of Maya culture. Besides totally destroying farmlands and villages in the most severely impacted zone around the volcano and disrupting agricultural production over a vast region, the eruption may also have been responsible for a massive redistribution of the Maya population, causing an estimated 320,000 survivors to migrate northward from Salvador to Belize and northern Guatemala. The influx of migrants, displaced by the Ilopango event, may have been a catalyst that helped accelerate the already in-progress development of Classic Maya civilization. Flooding lowland towns and villages north of Ilopango, these tens of thousands of refugees may have stimulated rapid social and political responses by the Maya leadership to accommodate the suddenly increased populations. After the eruption forced abandonment of the major highland trade route, rulers at Tikal gained control of regional commerce.

Excavations at sites scattered over central and western El Salvador which were affected by the Ilopango cataclysm reveal a wealth of Preclassic Maya artifacts. Located about 40 miles from Ilopango, pre-eruption Chalchuapa was a major residential, economic, and ritual center in the southeast Maya highlands, featuring numerous 50 foot high pyramids arranged around open plazas and elaborately sculptured monuments, some of which bore calendric dates. Numerous ceramic vessels, some with polychrome painting, were found under Ilopango's ubiquitous layer of light-colored ash, known locally as the *tierra blanca*. Digs at rural sites have uncovered farms, fields (many apparently irrigated), and villages. The ruins of a farmhouse at the village of Joya de Ceren, buried under 16 feet of ash, disclosed much about the Maya villagers' diet and way of life, indicating that they ate corn, wild and domesticated beans, and squash, liberally spiced with an array of chilies. Enjoying a variety of shellfish, they cooked their food in cottonseed oil and wove cotton cloth that they may have traded for obsidian, a desirable raw material for tools in the New as well as the Old World.

B. Mount Arenal and the Prehistoric Culture of Costa Rica

In contrast to the long-term effects of the Ilopango disaster, repeated eruptions of the Mount Arenal in the rainforests of northwest Costa Rica do not seem to have had a significantly disruptive impact on the native population. Sheets' investigations around Arenal, one of Central America's most active volcanoes, indicates that village life, established about 2000 B.C., was remarkably

stable. Despite at least nine explosive outbursts during the prehistoric period, villagers were resilient and maintained permanent settlements near the volcano. Whereas the Ilopango paroxysm was large enough to generate massive changes in Mayan society and mark a definable boundary between distinctive phases of Mayan cultural development, the frequent Arenal eruptions—averaging four per century—did not effect a comparable alternation in the culture of prehistoric Costa Rica. Aerial photographic surveys and digital remote sensing devices have detected numerous linear anomalies in the region, many of which have been identified as prehistoric footpaths, representing a long-established system of transportation and communication through the rainforests that persisted in spite of Arenal's many explosive eruptions.

VI. NORTH AMERICAN ARCHAEOLOGICAL SITES

A. Eruptions at Sunset Crater, Arizona

In the southwestern United States, native peoples pursued a sedentary existence and farmed land near the present site of Flagstaff, Arizona, since at least A.D. 600. Then, during the 1060s, Strombolian eruptions formed Sunset Crater, blanketing the landscape with tephra and emitting a series of lava flows that buried previously arable fields. Until recently, anthropologists believed that tephra ejected during the eruptions greatly enhanced the soil's fertility, causing large number of Native Americans from other territories to flock to the posteruption Sunset area. Reexamination of the archaeological evidence, however, indicates that the presumed population increase is illusory; instead of other cultural groups migrating to cultivate the ash-enriched fields, the indigenous peoples merely transferred their settlements to new locations near the cinder cone, readjusting their practices to cope with the volcanic changes wrought in the physical environment. Unusually heavy rains that characterized the three decades following the ash eruption probably accounted for the Sunset area's posteruption increase in crop productivity, not deposition of the ash itself.

B. Native American Site Near Mount Rainier, Washington

Most of the world's archaeological sites conserved by volcanic activity are those rapidly buried by tephra or

pyroclastic flows. By contrast, lava flows typically crush, pulverize, and/or burn man-made structures in the process of covering them. Similarly, most volcanic debris flows and lahars, which resemble churning wet concrete as they stream downslope, also destroy more than they preserve. A rare exception is a Native American settlement in the Cascade Range foothills of western Washington, near the present towns of Enumclaw and Buckley (Fig. 4). Discovered in 1972, the prehistoric campsite contained numerous stone projectile points, scrapers, and other tools, as well as charcoal that helped to fix the date of its burial. The encampment, located on what was then a hilltop above a valley floor, was engulfed almost instantly by an enormous lahar, the Osceola Mudflow, generated when an explosive eruption caused the former summit of Mount Rainier to collapse (Fig. 5). Almost a cubic mile of rock, much of it hydrothermally altered, avalanched down the volcano's northeast flank

and was transformed into a thick lahar as it traveled more than 65 miles down the White River Valley, beyond the Cascade mountain front, where it easily swept over the hilltop camp, and ultimately into an arm of Puget Sound. Although the Osceola Mudflow had transformed the area beyond recognition and many centuries elapsed before native peoples reoccupied it, a new settlement was eventually established directly above the buried site. Two thousand years older than Akrotiri, this collection of native artifacts is one of the oldest evidences of human culture in the Puget Sound region.

C. Effects of the Mount St. Helens "Y" Tephra

As the most frequently and violently explosive volcano in the 48 contiguous states, Mount St. Helens in southwest

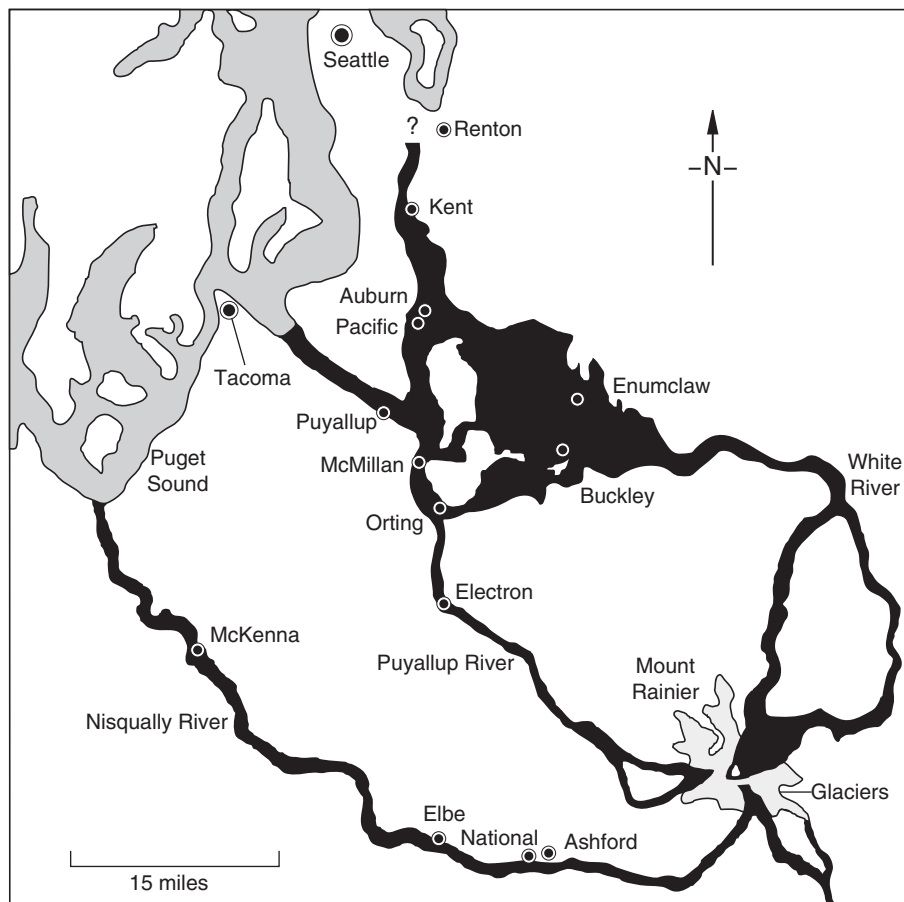


FIGURE 4 Map showing hazard zones for mudflows (lahars), lava flows, and pyroclastic flows from Mount Rainier, Washington State. About 5600 years ago, the volcano's former summit collapsed, generating the Osceola Mudflow that buried an Indian encampment near the present town of Buckley, preserving the oldest known human artifacts in the Puget Sound region. More recent mudflows followed the channels of the Puyallup and Nisqually Rivers, inundating areas where tens of thousands of people now live. (From U.S. Geological Survey Open-File Report 98-428).



FIGURE 5 Mantled by a cubic mile of glacial ice, Mount Rainier (14,411 feet) towers above the densely populated Puget Lowland of western Washington State. Considered the most potentially dangerous volcano in the 48 contiguous states, Rainier has repeatedly produced massive debris flows, some of which have inundated areas where hundreds of thousands of people now live. (Photo by Austin Post, U.S. Geological Survey.)

Washington apparently affected the settlement patterns of some Native Americans. About 3600 years ago, St. Helens began a series of intermittent outbursts that produced the “Y” (yellow) tephra sequence, pumiceous deposits mantling much of the Pacific Northwest. Although the degree of environmental degradation to the affected areas is not known, comparisons with similarly voluminous eruptions at other volcanoes indicate that a heavy fall of coarse lapilli typically defoliates trees, smothers vegetation, pollutes water sources, and depletes both animal populations and the human predators who depend on them. Recent studies by the U.S. Forest Service and others indicate a hiatus in settlements throughout the southwest Cascade Range between about 3600 and 1600 years ago. During approximately the same period, there was a coincidental increase of native populations in the Columbia Plateau to the east, a shift perhaps attributable to St. Helens’ repeated ejections of tephra.

D. Effects of the White River Ash on Native Inhabitants of the Yukon

The White River Volcano, located in southeastern Alaska near the headwaters of the White River, produced two cataclysmic eruptions, about A.D. 20 and A.D.

720, that covered most of the southwestern Yukon Territory with voluminous ashfalls. Anthropological studies indicate that the later and larger of the two outbursts, which deposited the east lobe of the White River Ash, caused profound disruption of the native population, possibly initiating a series of migrations that culminated in the formation of the Pacific Athapaskans in British Columbia and of the Apache and Navajo of the southwestern United States. Athapaskan lore, transmitted orally for more than 1200 years, refers to fiery explosions and a collapsing mountain that caused the people’s ancestors to abandon their original homeland and, in small bands, eventually drift westward or southward to their present locations.

One of the world’s most active volcanic regions, the Aleutian Range of Alaska hosts at least 45 historically active volcanoes. Studies of peoples inhabiting the Aleutian Islands during the 18th century A.D. indicate that eruptions, including submarine activity, have repeatedly influenced the movements of native inhabitants. Dependent exclusively upon marine fauna for their existence, the Aleuts have apparently been forced to abandon settlements destroyed by tsunamis generated during earthquake-induced underwater landslides or submarine eruptions. In some cases, it appears that the Aleuts have deserted settlements because underwater activity killed the sea life that constitutes their sole food supply.

VII. GEOMYTHOLOGY: VOLCANOES IN PREHISTORIC ORAL TRADITIONS

A. Greco-Roman Myths

Dealing with the social customs and belief systems of ancient cultures, as well as their tangible remains, archaeology encompasses the relatively new discipline of geom mythology, the study of oral traditions that perpetuate memories of prehistoric geologic events, such as earthquakes, floods, and volcanic eruptions. Geom mythology provides not only some of humanity's oldest surviving verbal responses to volcanic activity but also some basic terminology for describing volcanic phenomena. The term "volcano" derives from the name of Vulcano, an Aeolian island in which Vulcan, the Roman god of fire and metalcraft, was believed to have set up his blazing smithy. When busy working, Vulcan employed a giant bellows that roared and sent huge sparks rising skyward. Vulcan's earlier Greek counterpart, Hephaestus, similarly a god of fire and the forge, was said to have landed on the volcanic island of Lemnos when Zeus, king of the Olympian gods, threw him from heaven, presumably accounting for the long-lived thermal activity there.

As the tale of Vulcan's noisy workshop implies, the myths of classical Greece and Rome reflect the volcanic nature of the eastern Mediterranean. In his *Theogony*, an epic poem about the origin of the Greek gods, Hesiod (c. 750 B.C.) describes a cosmic battle between Zeus and his giant enemies, the Titans, that depicts the conflict as it were a violently explosive eruption, perhaps a mythic echo of the Thera paroxysm. Hesiod also narrates Zeus's defeat of another fiery opponent, the dragon Typhoeus, using similar volcanic imagery. According to the dramatist Aeschylus in his *Prometheus Bound*, Zeus finally imprisons Typhoeus, an embodiment of primal chaos, under the bulk of Mount Etna, Europe's largest and most active volcano. Aeschylus's etiological account thus explains Etna's outbursts as Typhoeus's struggles to escape his subterranean prison, his fiery breath melting rock to produced outpourings of lava that endanger human settlements.

B. A North American Myth: The Formation of Crater Lake, Oregon

The largest Holocene eruption in North America, that which decapitated Mount Mazama about 7500 years ago

to form the caldera holding Crater Lake in the Cascade Range of southern Oregon, deposited ash over a half million square miles and, without a doubt, had an impact on the lives of countless prehistoric Native Americans. Although researchers have not yet been able to correlate the physical effects of Mazama's eruption on the flora and fauna of eastern Oregon, native survivors of the volcanic holocaust apparently were so deeply impressed by it that they created an exceptionally long-lived oral tradition about the event. However improbable it seems, oral accounts of the eruption must have been transmitted through approximately 250 generations!

In 1865, Lalek, an aged member of the Klamath tribe, told William M. Colvig, then a young soldier stationed at Fort Klamath, Oregon, the story of a battle between Llao, an underworld deity who inhabited Mount Mazama, and Skell, a sky god who dwelt atop Mount Shasta, 125 miles to the south. Although it ascribes volcanic phenomena to the tempestuous rivalry between two supernatural figures, Lalek's tale includes geologic facts then unknown to white settlers, including the extreme devastation wrought by Llao's flaming mountain and its subsequent collapse to create the basin now occupied by a lake almost 2000 feet deep. The fact that Mazama once towered high above neighboring peaks and that its former summit subsided rather than blew apart was not generally recognized by geologists for many decades after Lalek's time.

C. The "Bridge of the Gods" and Cascade Volcanism

About 200 miles north of Crater Lake, native tribes living along the Columbia River Gorge of the Pacific Northwest transmitted to early missionaries other ancient myths involving seismic and volcanic events. Perhaps the best known of these concerns the "Bridge of the Gods," a natural formation that reputedly once spanned the Columbia River near the present site of Cascade Locks, Oregon. Although it is probably now impossible to disentangle later embellishment and Caucasian interpretation from the original tradition, a Klickitat account reflects some of the region's actual geologic history. According to Klickitat storytellers, long before white people appeared on the scene, native tribes were able to cross the Columbia via a land "bridge" that was *romanowos*, a creation sacred to the gods. But when the tribes became greedy and quarrelsome, *Tyee Sabale* (commonly translated the Great Spirit) took steps that eventually led to the bridge's destruction. First, he

caused all the fires in their lodges to go out. Only the fire maintained by Loowit, an aged lady who avoided the violence that divided her people, remained burning, so that all her neighbors had to come to her to reignite their campfires. When *Tyee Sabale* asked Loowit to name a reward for her generosity, she instantly demanded youth and beauty. Transformed into a lovely young woman, Loowit inadvertently rekindled the fires of war, attracting two intensively competitive brothers, Pahto, who ruled over territory north of the Columbia, and Wyeast, who led the Willamette people south of the river.

When Pahto and Wyeast contended furiously for Loowit's favor, hurling red-hot boulders at each other, *Tyee Sabale* separated them by destroying the *tomanowas* bridge linking their two territories, its fragments creating the cataracts for which the neighboring Cascade Range was later named. The Great Spirit also changed the three principals of this love triangle into volcanic mountains: Pahto became the broad-shouldered giant that white settlers called Mount Adams; Wyeast became Mount Hood; and Loowit, Mount St. Helens. Although St. Helens's two alpine suitors repeatedly thundered their passion, the temperamental St. Helens (whom some tribes named *Tabonelatclah*, fire-mountain) remained active longest, her 1980 outburst continuing the lovers' saga into the late 20th century.

An etiological myth explaining the eruptive behavior of three sentinel peaks guarding the lower Columbia, the Bridge of the Gods tradition also evokes memories of an enormous avalanche (the Bonneville Landslide) that completely dammed the river between about A.D. 1100 and 1250, forming a causeway that allowed the Indians to cross the river dry-shod. (Because the local tribes had no word for "bridge," the notion that this formation was a soaring natural arch is a Caucasian invention.) It is possible that some of the large basaltic blocks forming the landslide dam remained in place long after the river cut a new channel through its southern toe. If so, the famed Bridge of the Gods was in fact a chaotic pile of lava slabs (a native leader described the formation to a French missionary as "a long range of towering and projecting rocks") before it collapsed, possibly in the Cascade Subduction Zone earthquake of January of A.D. 1700.

VIII. SUMMARY

In many important ways, volcanoes have proven a boon to the science of archaeology. Widespread deposits of

ash create valuable time-markers, helping to date artifacts associated with a distinctive ash layer. Unusually large eruptions of tephra that have been dated by radiocarbon or other methods, such as those produced by the Thera volcano (traces of which have been found from eastern Crete and the Aegean sea floor to central Turkey) and Oregon's ancient Mount Mazama (which mantled almost the entire Pacific Northwest and southwestern Canada), can provide even greater precision in dating objects found directly covered by the tephra. Because even exceptionally large explosive eruptions typically last for only a few hours or days, in a single moment of time, they are able to bury nearby cities and other settlements with great rapidity, preserving, as at Pompeii, Herculaneum, and Akrotiri, the whole gamut of a culture's material artifacts. Volcanic outbursts also inspire survivors to create richly imaginative traditions about the supernatural forces that precipitate such terrifying manifestations of power, generating some of the world's most intriguing myths.

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