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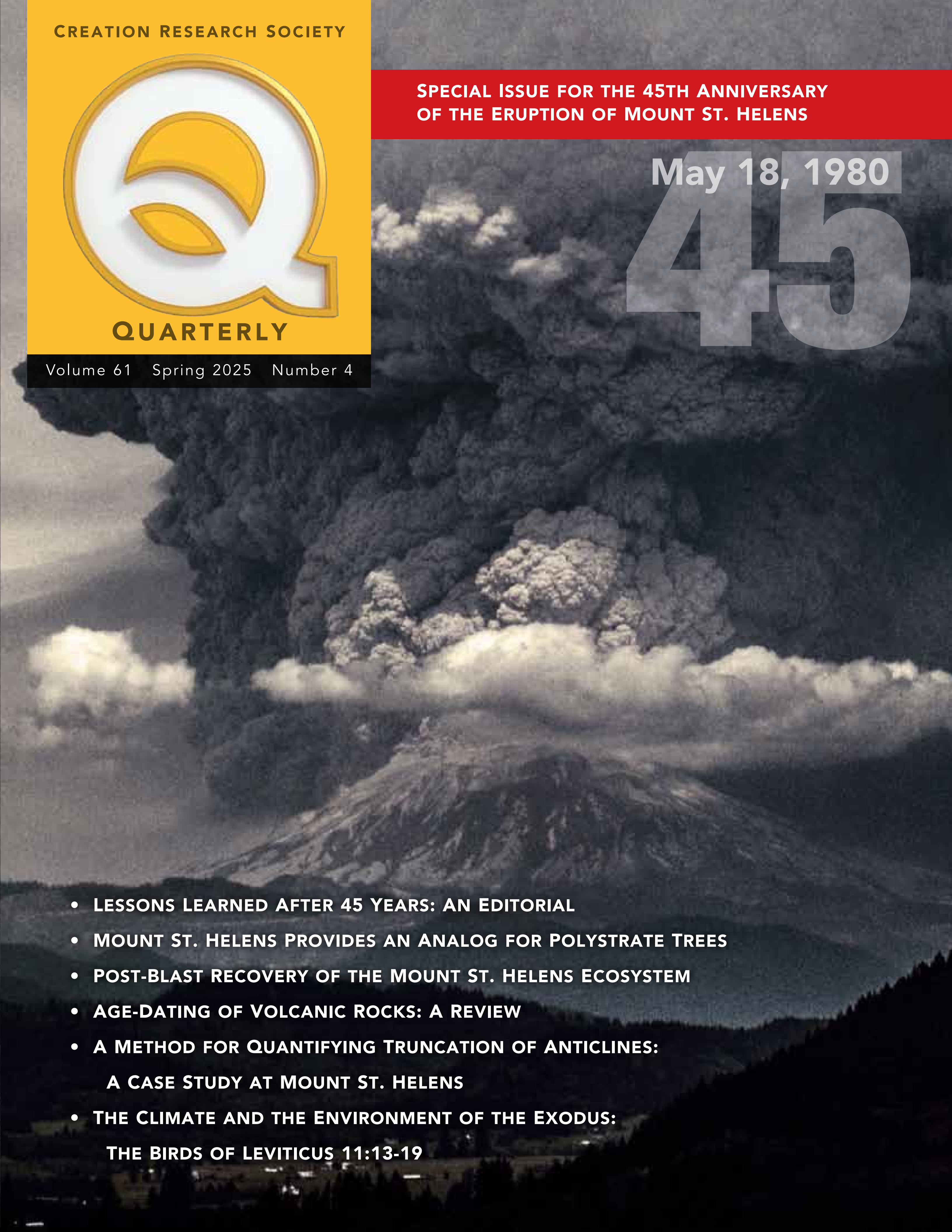
SPECIAL ISSUE FOR THE 45TH ANNIVERSARY
OF THE ERUPTION OF MOUNT ST. HELENS



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Haec Credimus

For in six days the Lord made heaven and earth, the sea,
and all that in them is, and rested on the seventh. —Exodus 20:11

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Editorial

Lessons Learned After 45 Years

This issue of *CRSQ* commemorates the 45th anniversary of the May 18, 1980, eruption of Mount St. Helens. I was an undergraduate studying geology at the time. I recall the excitement the following Fall as my geology professors discussed the eruption and its aftermath. Little did they know how much it would change their thinking. It even changed their teaching.

Prior to this eruption, strict uniformitarianism reigned supreme in geology. The influence of James Hutton and his concept of deep time had trickled down to the smallest details. But the eruption of Mount St. Helens changed that in the blink of an eye.

Drs. Steve Austin and John Morris, and several others, led the creation-science charge. They visited Mt. St. Helens numerous times following the initial eruption in 1980 and again after the smaller 1982 eruption. They even scuba dove in Spirit Lake to study the post-eruption log mat!

They found that up to 400 feet of new strata had formed during the eruption in 1980 (Austin, 1986). These deposits originated from air fall, pyroclastic flows, landslides, and even stream water. They discovered that finely laminated deposits can be produced in a matter of minutes. Previously, laminated strata were believed to take many years to form, with possibly one layer deposited each year. But Mount St. Helens demonstrated that this is not true. Instead, it was shown

that a 25-foot thick, finely laminated unit was deposited in a matter of hours (Austin, 1986).

Secondly, creation scientists observed that erosion can occur much faster than conventionally thought. Scour from the steam blast, ash flows, and mudflows rapidly changed the landscape surrounding the volcano and its waterways. The North Fork of the Toutle River had to carve a new course following the 1980 eruption because it was blocked by nearly a cubic mile of debris (Austin, 1986). After another small eruption on March 19, 1982, a mudflow from melted snow and ice carved a new 140-foot deep canyon down the flank of the volcano (Austin, 1986). This "Little Grand Canyon" is an approximate 1/40th scale version of the Grand Canyon. It demonstrates the scouring power of water. Creation geologists frequently use this new canyon as an analogy for the rapid formation of the much larger Grand Canyon. The global Flood provided ample water to carve canyons and erode rocks in a short amount of time. Even conventional scientists now realize that erosion can be much faster under the right conditions. In this issue, there is a paper by E.A. Isaacs that examines the rapid erosion of folded rocks using a case study from Mount St. Helens.

In 1992, Dr. Austin collected a seven-kilogram sample from the igneous dome that had formed in the crater of Mount St. Helens from 1980–1986 (Austin, 1996). The porphyritic dacite sample, as geologists call it, was broken and processed into five samples, one whole rock and four mineral concentrates. Conventional radioisotope methods gave a K-Ar age of about 350,000 years for the whole rock sample, whereas the mineral concentrates gave K-Ar ages ranging from 340,000 years to 2.8 million years (Austin, 1996). These inconsistent and outlandish results for a rock about a decade old question the accuracy of the K-Ar method and radioisotope dating in general, and for good reason. In this issue, there is a paper that reviews many of the inconsistencies and problems with age-dating volcanic rocks by Andrew Snelling.

Creation scientists also found that the massive landslide that initiated the eruption in 1980 sent about 680 million cubic yards of material into nearby Spirit Lake. This caused a gigantic tsunami that ripped across the hillsides north of the lake (Morris and Austin, 2003). The tsunami carried back an estimated 1 million trees to the lake as the water returned. Many of these trees were found to be floating upright with the heavier ends down. By 1985, it was estimated that more than 19,000 upright logs had settled on the floor of the lake (Austin, 1986).

Dr. Steve Austin discovered that many of the trees had settled at various levels in the mud, giving the appearance of deposition at different times. But all of these trees were washed into the lake at the same moment. These observations explain the multiple layers of upright petrified trees found at different stratigraphic levels at Specimen Ridge in Yellowstone National Park (Morris and Austin, 2003). The trees at Spirit Lake demonstrate that all of these petrified trees could have formed at about the same time, merely sinking into different layers. In this issue, there is a paper by Michael Oard that reviews many other sites where fossil trees have been found upright and rootless.

The rapid biological recovery at Mount St. Helens is another topic of study for creation biologists. It has been used as an analog for post-Flood recovery by many authors. In this issue a new paper by Harry Sanders, Michelle Mannisto, and Autumn Double examines the state of the post-eruption recovery at Mount St. Helens.

Mt. St. Helens has provided 45 years of empirical data that support catastrophism and refute uniformitarianism. The eruptions have changed the way evolutionary scientists view Earth's processes by making them more accepting of catastrophism. Creation scientists can still use the events and the processes at Mt. St. Helens as an outdoor laboratory to study the devastating effects of the global Flood.

I encourage you to read all of the papers related to Mount St. Helens in this special issue of *CRSQ*. After 45 years, Mount St. Helens continues to provide strong evidence for a recent global Flood.

Tim Clarey
Editor

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Mount St. Helens Provides an Analog for Polystrate Trees

Michael J. Oard

Abstract

The floating logs on Spirit Lake from the 1980 eruption of Mount St. Helens are briefly described. Over the years, some sank vertically to the bottom while heavy sedimentation occurred. This provides an analog for the Yellowstone fossil "forests" that has caused some who claimed to be Christians to become agnostics or atheists, such as Ronald Numbers. It also can explain vertical petrified trees at many other locations. The log mat on Spirit Lake provides an analog for log mats formed during the Flood.

Key Words: Log mat, Mount St. Helens, Noah's Flood, Ronald Numbers, Spirit Lake, Yellowstone fossil 'forests'

Introduction

The May 18, 1980, eruption and following eruptions of Mount St. Helens was a boon for creation scientists (Morris and Austin, 2003). It showed how one small eruption could provide insight into Noah's Flood. One of the more surprising aspects of the eruption was the formation of hundreds of thousands of logs floating on Spirit Lake.

The Floating Log Mat on Spirit Lake

Spirit Lake is located about 9 km north of Mount St. Helens. On May 18, 1980, a magnitude 5.1 earthquake cause the failure of the oversteepened north slope of Mount St. Helens causing the eruption (Austin, 1987, pp. 3–9; Morris and Austin, 2003). The northward-orientated blast toppled trees over an area of 380 km^2, and the landslide displaced Spirit Lake causing a huge wave to wash 260 m up the north slope of Spirit Lake. The wave washed hundreds of thousands of trees sheared off from the blast down into the lake. A log mat larger than 5 km^2 ended up floating on top of the lake. Figure 1 shows the log mat in 2005, 25 years after the blast.

As the trees became waterlogged, some began floating in a vertical position as the heavier end sank to the bottom. Sidescan sonar and scuba photography both show that many of the logs settled to the bottom in a vertical (growth-like) position. Extrapolating from a small area of the lake surveyed, Morris and Austin (2003) and Coffin et al. (2005, p. 245) estimated 20,000 upright stumps had been buried in the bottom of the lake in the first five years since the blast. Because significant sedimentation continued largely from heavy rainfall eroding the barren landscape around the mountain, the upright logs became lodged in the sediment at different stratigraphic levels.

Imagine if Mount St. Helens erupted so long ago that Spirit Lake had filled with sediment. If the varying

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levels of upright logs were exposed, how would secular scientists interpret what they find? They would likely be seen as successive forests that grew and became buried by successive debris flows. This could have gone on for many thousands of years. But this would be a wrong interpretation built upon wrong assumptions. Instead, what happened in 1980, provides an alternative for understanding the deposition of vertical trees in multiple layers. For example, this new understanding can be applied to the numerous levels of upright logs discovered in Yellowstone National Park (Oard, 2014) and other places.

The Yellowstone Fossil "Forests"

Prior to the eruption at Mount St. Helens, the Yellowstone National Park fossil "forests" were a significant challenge for Flood geology (Sarfati, 1999). The multiple layers of polystrate trees were believed to represent multiple forests that grew, died, were buried by volcanic debris flows, and the next forest established, similar to the conventional story. Each cycle was said to take about 500 years. Since there are a few dozen levels of vertical petrified trees at Specimen Ridge (Figure 2), this would represent about 12,000 years. For the 65 levels at Specimen Creek (Figure 3), the time represented would be approximately 32,500 years assuming the 500-year average. (Specimen Creek is not associated with Specimen Ridge. The former is in the extreme northwest corner of Yellowstone while Specimen Ridge is in northeast Yellowstone National Park.) Obviously, if this model were true, the time necessary would eliminate the young-Earth timeline for Biblical history.

Because of the deep time implied by the successive levels of vertical trees, the Yellowstone fossils forests have been mentioned often by uniformitar-

Figure 1. Spirit Lake with Mount Rainier in the background as seen from the crater of Mount St. Helens (Matt Logan, USGS photograph).

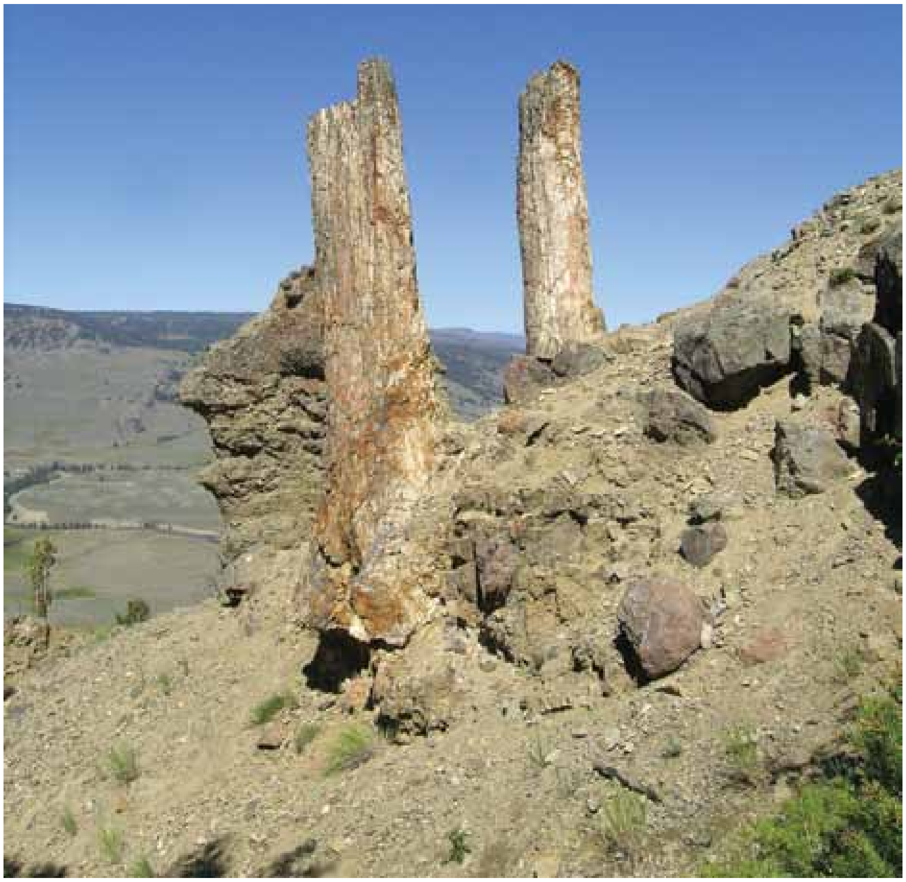

Figure 2. Close up of the volcanic breccia with two petrified trees at the top of Specimen Ridge, Yellowstone National Park, USA.

Figure 3. Absaroka volcanic breccia layers showing many levels of petrified trees at Specimen Creek, Yellowstone National Park, USA.

Figure 4. Horizontal logs in Absaroka Volcanics on Mount Hornaday northeast Yellowstone Park, USA (Dr. Harold Coffin provides scale).

ian scientists as an "insurmountable problem" for Flood geology:

> This site and its long-age interpretation has been one of the most effective arguments which purport to show that the earth is older than biblical chronology will allow. It has convinced many that the Bible cannot be trusted and thus can be disregarded. (Morris and Austin, 2003, p. 100)

Ronald Numbers (2006), in his rather biased history of young-Earth creationism, wrote in *The Creationists*, that the fossil "forests" of Yellowstone persuaded him to discard Biblical Earth history:

> Born and reared in a fundamentalist Seventh-day Adventist family of ministers, I learned [George McCready] Price's version of earth history at my parents' knees. I subsequently attended Adventist church schools from first grade through college, and though I majored in science, I saw no reason to question the claims of strict creationism. In fact, I do not recall ever doubting the recent appearance of life on the earth until the late 1960s, while studying the history of science at the University of California at Berkeley. I vividly remember the evening I attended an illustrated lecture on the famous sequence of fossil forests in Yellowstone National Park and then stayed up much of the night with a biologist friend of like mind, Joe Willey, first agonizing over, then finally accepting, the disturbing likelihood that the earth was at least thirty thousand years old. Having thus decided to follow science rather than Scripture on the subject of origins, I quickly, though not painlessly, slid down the proverbial slippery slope toward unbelief. In 1982, when attorneys for both sides in the Louisiana creation-evolution trial requested my services as a

> possible expert witness, I elected to join the ACLU team in defending the constitutional wall separating church and state. In taking my pretrial deposition, Wendell R. Bird, the creationist lawyer who had tried to recruit me for his side, devoted two lengthy sessions to probing the limits of my historical knowledge and the thinness of my religious beliefs. On the basis of this inquisition, Bird publicly labeled me an "Agnostic." The tag still feels foreign and uncomfortable, but it accurately reflects my theological uncertainty. (Numbers, 2006, p. 13)

Note Numbers' initial reaction to the fossil "forests." He decided to follow "science" and not Scripture. In other words, without really trying

Figure 5. Vertical tree with two short, blunted roots in Absaroka Volcanics on Mount Hornaday northeast Yellowstone Park, USA (David Anderson provides the scale).

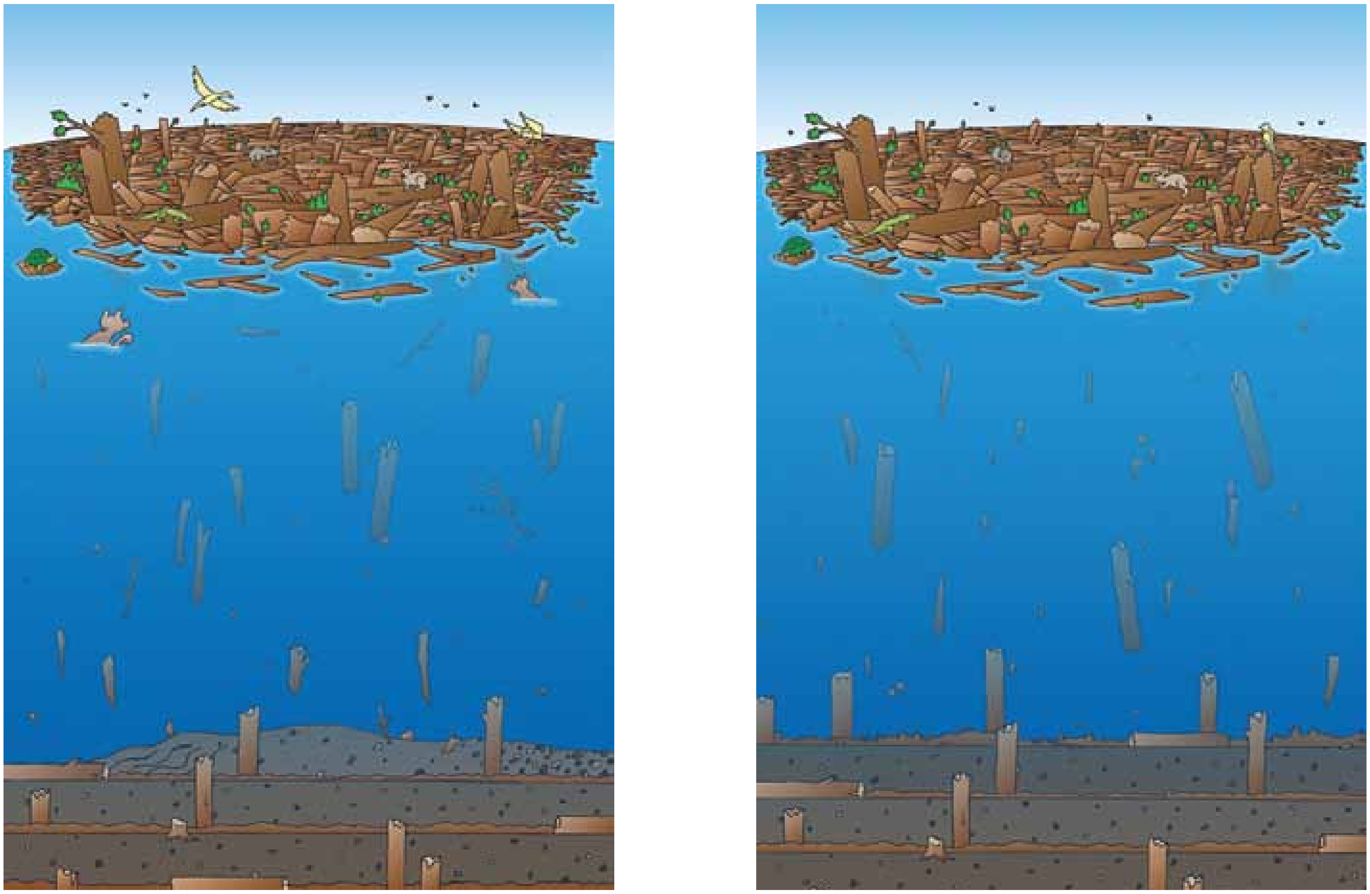

Figure 6. Schematic of a log mat with trees sinking vertically to the bottom, while the bottom is collecting deposits horizontally from volcanic debris flows.

to understand the full nature of the debate, he allowed one example of a phenomenon that he had not fully investigated to be the basis for his rejection of the historical account of Genesis and eventually the entire Bible.

It is worth noting that Numbers was following an *interpretation* of scientific observations that happened in the past (forensic science). He was not using the type of science that deals with present-day observations and repeatability (empirical science). This crucial distinction is poorly understood and seldom made by secular scientists. Unfortunately, many Christians accept their authority as scientists and fail to see the difference between observations we can witness today and interpretations of things that only happened in the past.

Had Numbers been patient and decided to investigate the fossil "forests" more carefully, he might not have jumped to such shaky conclusions. He should have acted like the Bereans in Acts 17:10–15, who checked Scripture to see what Paul said was true, and applied 1 Thessalonians 5:21: "…examine everything *carefully*; hold fast to that which is good" (NASB). If he had done so, he might have retained his faith, if he really wanted to retain it. This example shows us that we need to investigate geological and paleontological challenges *in depth* and not at the superficial level.

Dr. Harold Coffin and his colleagues from the Geoscience Research Institute in Loma Linda, California, did what Numbers should have done—they examined the data in the field to gather the facts (Coffin and Brown, 1983, pp. 134–151; Coffin, 1997; Coffin et al., 2005, p. 245). They spent many years conducting field research, refining a Flood model that explains the data without abandoning Scripture (Figure 6).

It is amazing that Numbers, who took the time to research and write a book about creationists, never mentions the work of Dr. Coffin and his associates. Had he searched the creationist literature, he would have discovered Dr. Coffin's research. This alone casts grave doubt on the scholarship of his book. All of Coffin's research was performed *before* the expanded edition of Numbers' book was published in 2006. Clearly, Numbers prefers the camp of the anti-creationists instead of serious investigation on his own, since the answer to his "insoluble problem" has been readily available in the literature for some time.

Many observations associated with the Yellowstone fossil "forests" are contrary to the idea of successive forests. First, the vertical petrified trees are within the (Middle Eocene) Absaroka Volcanic Supergroup (Figures 4 and 5) and part of the volcanic debris flow breccias in northern and eastern Yellowstone Park and adjacent areas. Breccia is a cemented rock composed of broken angular fragments. The Absaroka Volcanics extend over an area that stretches 250 km in a northwest direction from just north of Dubois, Wyoming, to just southeast of Bozeman, Montana. It covers more than 23,000 km^2 with a thickness that exceeds 1,830 m and a volume of about 30,000 km^3 (Sundell, 1993, pp. 480–506; Feely and Costa, 2003). Moreover, the breccia lacks soil horizons, and tree rings sometimes match across two or more levels, indicating they grew at the same time. In addition, pollen and trees found in the volcanic-rich rocks are from 200 different species ranging from the tropics to the colder temperate climatic zones. Bark and extensive root systems are rare, the wood is often weakly fossilized or unfossilized, the trees are commonly polystrate (crossing multiple layers) and not decayed at the top (as would be expected if exposed for an extended time), and lack animal fossils either within the trees or in the breccia as expected in a forest (Coffin, 1997; Morris and Austin, 2003).

Explains Other Locations with Vertical Trees

With the observational results from Spirit Lake as an example of the behavior of trees and vegetation after floating for many years, we can better address a problem that has long puzzled many scientists. Many areas have fossil trees buried in a vertical or upright position with respect to the sedimentary layers. Sometimes they form polystrate trees, which pass through two or more sedimentary layers, and are often observed in coal mines. This also suggests the rapid formation of coal, as opposed to the uniformitarian model of the slow formation of coal from a "peat swamp." Interestingly, nearly all of these trees are petrified.

Uniformitarian scientists typically assume these trees grew and were fossilized in situ. However, the tops of the trees are not decayed any more than the bases. This suggests that they did not stand exposed for extended periods of time before their complete burial. And most show no root systems as would be found if buried in situ. Nonetheless, they are forced to claim local and rapid burial of the trees, although the strata can often be traced over vast areas, suggestive of a more extensive flooding event. Instead, all of the vertical trees in these many locations are better explained by log mats during Noah's Flood.

Joggins Polystrate Trees

One location where polystrate trees can be observed is the famous Joggins Formation of Nova Scotia where there are numerous vertical trees and casts of trees (Morris, 1999, i.–iv.; Juby, 2006, 2009, pp. 217–230). The site has at least 76 coal seams ranging in thickness from 0.05 to 1.5 m and 63 "forested"

Figure 7. A polystrate tree penetrating more than one layer of sedimentary rock from the Joggins Formation, Nova Scotia (photo courtesy of Ian Juby).

Figure 8. Two polystrate trees, up to 4 m tall, from a coal mine north of Sutton, Alaska.

horizons (defined by the levels where vertical trees are found) as described by Waldron and Rygel (2005). The upright trees include lycopods 5 to 6 m tall. One lycopod cast reaches 12 m. Figure 7 shows one of these fossil trees. Where the base is observed, it appears to have no roots or soil horizon.

Ginkgo Petrified Forest State Park

A spectacular, but less known site of petrified polystrate trees is the Ginkgo Petrified Forest State Park in Washington, just north of Vantage on Interstate 90 along the Columbia River (Coffin, 1974; Coffin and Brown, 1983, p. 213; Oard, 1995). The layers are within basalt lava flows and thin sedimentary interbeds within the Columbia River Basalt flows of eastern Washington. A number of petrified trees, some quite wide, can be observed on a nature walk at the park. Some of the trees are vertical and some are buried in the basalt at an angle and do not appear to be burned by the heat of the lava. As far as I know, the bases of these trees are not exposed, but the fact that many are tilted at an angle to the basalt flows indicates that it is likely the trees did not grow there.

An Alaskan Coal Mine

Polystrate trees have been observed in three open-pit coal mines about 7 km north of Sutton, Alaska, about 80 km northeast of Anchorage (Oard and Giesecke, 2007). The polystrate trees were found at *different levels* in the mines. Derek Ager (1993, pp. 47–49) pointed out that vertical trees are not uncommon in Carboniferous coal. Figure 8 show two of these polystrate trees with the base exposed, showing no roots and likely no associated soil.

Florissant Petrified Stumps

Massive, petrified sequoia or redwood stumps in vertical position have been found at Florissant Fossil Beds National Monument in Florissant, Colorado (Figure 9) (Oard, 2019). These are probably the largest-diameter petrified tree stumps in the world. Based on an explanatory plaque, one is more than 4 m in diameter and represents less than 1,000 years of growth. No roots were observed at the base of this petrified tree. It is possible that the centers of the large trees are not petrified as observed at the site. The location is west of Pikes Peak at an elevation of 2,485 m in Colorado's Rocky Mountains. In addition to the fossil trees, geologists have found 1,500 species of insects and spiders (McLeroy and Anderson, 1966; Meyer et al., 2004, pp. 151–166) and 150 species of plants in the thin-bedded sedimentary rocks in the area (O'Brian et al., 2002).

Figure 9. Vertical Redwood tree at Florissant Fossil Beds National Monument in Florissant, Colorado.

Figure 10. Portion of one layer of vertical petrified trees in the "fossil forest" of Theodore Roosevelt National Park. Peter Klevberg pointing to the lack of soil under the vertical tree stump.

Numerous Petrified Stumps in Theodore Roosevelt National Park

The last area mentioned is the hundreds of polystrate tree stumps about 1 to 2 m tall found in Theodore Roosevelt National Park. Because of the intense erosion of the surrounding badlands, the base of the trees and presumably the material the trees grew in are well-exposed (Oard and Klevberg, 2022). Many once-vertical trees had already toppled because of more recent erosion. Most trees had a bulbous base and are of the species *Metasequoia glyptostroboides* or dawn redwood, a common type of tree found as a fossil.

Oard and Klevberg (2022) noticed that the trees were not only truncated at the top, as if sheared off by a powerful wind, but also the bottom had no roots and no evidence of a soil horizon underneath (Figure 10). There are also areas within the national park and in southwest North Dakota and northwest South Dakota with many logs without stumps.

It is interesting that at one time the *Metasequoia* tree was thought extinct, the last fossil is found in Pliocene layers, claimed to be over 2.5 million years ago, but it was found alive in 1941 growing in a remote area of southern China (Bartholomew et al., 1983). It is considered a "living fossil," and the question can be asked, where are the fossils of this common tree between 2.5 million years ago and today? The same can be asked of other living fossils. If the millions of years claimed by conventional science are real, why don't we find these tree fossils at least somewhere in Pleistocene time?

Upside-Down Trees

A rare, but provocative, line of evidence for transported trees is the upside-down polystrate trees. Rupke (1970, p. 155) stated: "And, what's more, examples [of vertical trees] are found which appeared to be *upside down*, or, in other words, which have their root end uppermost." Coffin et al (2005, p. 203) show a picture of an upside-down tree from a large coal seam in Australia (Figure 11). Upside-down polystrate trees should be evidence that the trees did *not* grow in place but were transported. The only other possibility is that the entire sedimentary column in the area was overturned; something that should be easily determined by physical field evidence.

Log Mats in Noah's Flood

The catastrophe at Spirit Lake was very small compared to the global scale of the Flood. Instead of destroying vegetation over a several hundred square kilometers, the Flood obliterated vegetation over the entire land surface of the planet. Therefore, it is easy to suppose that in the initial stages of flooding the pre-Flood land, billions of trees as well as large amounts of other plant material could have floated on the surface of the Floodwaters as well as become buried in the sediments to create future coal beds. Much of this vegetation would have been broken and buried due to the violence and the water currents of the Flood. Mount St. Helens, on the other hand, gives us a recent example of the power and work of a local catastrophe:

> …the eruption of Mount St. Helens, with its effects on surrounding forests, is proving to be a helpful model of what could happen to trees in a worldwide flood. (Coffin and Brown, p. 14)

Floating vegetation could have aggregated due to the effects of wind, waves, and currents. It would have formed tangled mats, which for simplicity's sake will hereafter be called "log mats," even though additional types of vegetation would likely have been included. Numerous mats were likely present during the Flood, and some would have been carried long distances by currents and winds. Smaller mats probably coalesced to form larger ones, while at the same time, some mats were likely constantly losing pieces of vegetation as they became waterlogged, sank, and are buried in Flood sediments. Log mats from different climatic regimes could conceivably mix. And of course, some of these violent waves buried entire mats of vegetation to later become coal beds, some of which were 100 km by 100 km and up to 60 meters thick as in the Powder River Basin of Wyoming (Clarey et al., 2021).

Such a Flood model can help explain the Yellowstone fossil "forests" (Coffin, 1997; Oard, 2014). Comparing the observations at Yellowstone National Park with those at Spirit Lake and elsewhere, provides a basis for understanding examples in the rock record like the Yellowstone fossil "forests." Coffin (1997, p. 39) concluded:

> A transport model involving the flotation of trees and organic debris in a body of water, as illustrated in Spirit Lake, gives a better fit to the data as observed in the Yellowstone Petrified Forests. We propose that the Yellowstone Petrified Forests provide an example of catastrophic deposition.

Figure 6 provides a schematic of how trees can sink from a log mat while the bottom is filled with multiple volcanic debris flows.

Conclusions

The floating logs on Spirit Lake north of Mount St. Helens provide an excellent analog for how to explain numerous locations with vertical trees that are found in various places all over the Earth. Upside-down trees provide evidence for this model. This analog can also explain multiple levels of vertical trees, like in Yellowstone National Park. It answers convincingly the strong challenge to the Flood by anti-creationists.

Figure 11. An upside-down petrified tree from a large coal seam in Australia (courtesy of Dr. Harold Coffin).

There is a more general lesson in this example for Christians. When challenged, we need to do a deep dive into the observations. Often, we will find the problem lies with the interpretation rather than the data. I have often found that when I gather the observations, any challenge to creation science is also a challenge to uniformitarianism. Half the time I can find an answer within Biblical Earth history. For the other half, and due to the complexity of the Flood, it may take years of research to find an answer. And, it is likely, we may never find a viable solution to some challenges, since we were not there to observe them. And we must always be aware that there will always be numerous unknowns in science, especially in the area of so-called historical science, in which paleontology and geology fall. But once in a while, our Creator, the Lord Jesus provides a solution before our eyes, as is the case for the eruption of Mount St Helens.

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Post-Blast Recovery of the Mount St. Helens Ecosystem

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Abstract

Forty-five years ago, Mount St. Helens, a long-dormant volcano, erupted. The aftermath of the tragedy presented scientists with a living laboratory to study the recovery of ecosystems affected by catastrophes. Ecosystem recovery has ramifications for the global Flood, which completely wiped away the existing Earth's ecosystems. Such a catastrophe has several overlaps with the Mount St. Helens eruption and thus gives creation scientists a window into ecosystem recovery from catastrophic conditions, such as those present during the Flood. In this paper, we examine the state of the Mount St. Helens ecosystem to determine whether it has recovered from the blast. Using species richness data from before the blast, and five subsequent time steps, we attempt to determine if Mount St. Helens is recovered, and, if so, what the implications are for the Global Flood Model as described in Genesis.

Key Words: diversity, ecosystem recovery, eruption, Global Flood Model, Mount St. Helens

Post-Blast Recovery of the Mount St. Helens Ecosystem

On May 18, 1980, Mount St. Helens in Washington state erupted. The eruption almost obliterated nearly 500 square kilometers around the mountain and caused ashfall miles from the blast zone, damaging standing forest that was not touched by the blast (Decker and Decker, 1981; Seymour et al, 1983). Tragically, many people were killed during the eruption. While a tragic result of our fallen world, the eruption allowed scientists to discover how an ecosystem recovers from a catastrophe. Such a recovery serves as a potential model system for recovery in the post-Flood world.

It is accepted among all young-Earth creationists that a global flood covered the surface of the whole Earth and completely reworked its topography. Some studies have been done in the aftermath of Mount St. Helens on the region's geology and with good reason (Austin, 1986; Morris and Austin, 2003; Austin, 2009; Walker, 2017). Mount St. Helens shows how the Flood might have changed the world. However, the attention of creationists has been largely focused on the geology of the region, not the biology, apart from three papers by Swenson (2018, 2020, 2021). No paper we could find has considered the question of the Mount St. Helen's ecosystem's recovery. Given that the creation model depends on rapid ecosystem recovery in the post-

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Flood world, including forming whole new plant ecosystems from seed, this question must be addressed. One study of volcanic recovery estimated roughly 2,000 years to reach full recovery (del Moral et al., 1996). The Flood was a far greater catastrophe than any volcanic eruption and, using the secularist methods, would doubtless take much longer.

Biological diversity cratered in the wake of the eruption. Even fifteen years after the eruption, satellite photos revealed many areas in the blast zone were under 20% maximum estimated cover (Lawrence and Ripple, 2000). Diversity took a corresponding dip (Crisafulli, Swanson, and Dale, 2005). Diversity was not, however, eliminated. Some species, particularly plants, survived in hollows and dips in the ground or behind ridgelines (del Moral, 2000). Areas with different exposure to mud and magma differed in how well existing organisms survived (del Moral, 1983). In one well-studied instance, a plant species, dependent on animals for dispersal, was genetically split in half, with about half the population being descended from blast survivors and the other half from outside immigrants (Yang et al., 2008). In most cases, new organisms arrived from outside the blast zone to recolonize the area (del Moral et al. 1995). However, by 2002, this had begun to change, as plants took root in the pumice plain and new communities emerged. Diversity began dropping as the ecosystem became stable (del Moral and Jones, 2002). The drop in diversity resulted from organisms well-suited to the post-volcanic landscape outcompeting earlier colonizers that may have been less-suited to the environment. Without competition, however, in the initial aftermath of the eruption, they could survive and propagate.

In the aftermath of the Mount St. Helens eruption, several regions emerged. The first of these regions was an area completely covered by volcanic pumice, aptly named the "pumice plain." Here, recovery was slow with one paper reporting a tiny number of plants living on the plain in 1988, mostly at lower elevations (del Moral and Wood, 1988). By 2010, five unique communities had been established in the pumice plain, and the plant community was becoming more homogenous (del Moral et al., 2012).

The second region was the tephra zone(s), where airborne volcanic particles settled thick enough to bury vegetation to varying depths. In these regions, recovery was also slow. Ten years after the blast, plant cover was substantially reduced in areas with extensive tephra, though some mosses thrived (Zobel and Antos, 1997). Zones with shallower tephra recovered more quickly than deeper areas, as might be expected, as it takes less time for plant roots to reach the underlying soil or for the tephra to erode to the soil level (Zobel and Antos, 1985). By 2005, areas that had been unforested had almost completely recovered, but forested areas had not (Crisafulli, Swanson, and Dale, 2005). Rates of recovery in these areas are somewhat site-specific (Fischer et al., 2019). Tephra zones also take the longest to reach 20% similarity to the original ecosystem (del Moral and Chang, 2015).

The third zone, the blowdown zone, recovered more quickly, likely because of lower eruption damage. Ground-cover species survived and quickly repopulated many areas (Halpern et al., 1990). Within 26 years, plant cover had reached as high as 70% in some sites (Halpern and Cook, 2018). Tree recovery, however, was below 6% cover in most cases in the same study. Other areas created by the eruption include the lahar mudflows, where early succession was not particularly influenced by nearby tracts of vegetation (del Moral, 1998). Environments tend to move toward homogeneity over time, as a form of stabilization (del Moral and Ellis, 2004).

In this study, we combined data from these and other areas within the blast zone to determine whether the diversity within the blast zone has reached levels similar to those existing before the blast. There are two main assumptions underlying in this research. The first assumption is that ecosystem recovery depends on the ecosystem's species richness and not the restoration of the specific species that existed before the blast. Thus, for this paper, ecosystem recovery depends on total species number and not species composition. Specific species-to-species interactions that defined the pre-1980 ecosystem may not be present in the modern ecosystem, yet they can still be considered recovered.

The second assumption is that if there is no significant difference between pre-blast and modern numbers of species within taxonomic groups, then the ecosystem is recovered. This is not necessarily the case. There could be, and likely are, areas within the blast zone where recovery is not complete. This is more likely the case in the pumice and heavy tephra regions, but there may be other places as well. The data we examined was from a top-down view of the whole ecosystem and thus may well miss the fine-grain details. Given the necessity of understanding post-catastrophe recovery and the paucity of work on the topic, it is crucial to understand the current state of the Mount St. Helens ecosystem.

Materials and Methods

For this study, we used species richness as a metric to determine if the Mount St. Helens ecosystem had recovered from the 1980 blast. Species richness is a common metric used in conservation to select areas to be conserved (Lelli et al., 2019). For our purposes, we wanted to compare the community before the blast with the community afterward. Species richness provided an excellent, easily accessible metric to compare the pre-blast environment with five separate post-blast time steps.

The dataset obtained from the citizen science website *iNaturalist* (2024) represents the observations of individuals in the Mount St. Helens region. Only data considered "Research Grade" (with three or more agreeing identifications) was used. Any observation with conflicting identifications was discarded to create the most accurate dataset. The *iNaturalist* data provided the bulk of the data for the modern portion of the dataset.

This data was combined with data from an extensive literature search for any organisms from the Mount St. Helens area. A full list of papers from which this data was obtained can be found in the reference section. The data was divided into six time steps, one representing a species presence before the blast, the others at the following post-blast dates: 1985, 1990, 2000, 2010, and the present.

Data was assigned to the time steps based on information in the papers. If the data was collected in 1986 or 2009, it was assigned to the 1985- or 2000-time step, respectively, as there was no guarantee that a species present in 2009 would survive into 2010. Thus, each time step represents a range of years. Any data from 2015 onward was assigned to the present. This represents a conservative approach, given that many species are present at a past time step, before missing a later time step and reappearing in the present. It is likely that those species mostly persisted in the Mount St. Helens ecosystem but were simply not documented. However, it is more conservative to assume their absence is real and not an artifact of incomplete data.

Once the data had been obtained, the number of species present in each group at each time step was tabulated. The genus, family, and order levels were examined to determine whether species richness in the environment had recovered after the blast. Paired t-tests were then performed for each level, comparing the number of species present in each group at time step one to the other five time steps. If the Mount St. Helens ecosystem has completely recovered its diversity, there should be no significant difference between the number of species present recently and the number present before the eruption. If, however, the difference is significant, it may mean recovery is not yet complete.

Fish were excluded from the analysis as they were absent from the *iNaturalist* data. Reptiles and mollusks were also excluded because *iNaturalist* did not contain enough data for analysis. Fungi, arthropods, amphibians, and birds lacked sufficient documentation prior to the blast populations to perform statistical analysis. Plants, however, make a good proxy for other organisms as species richness among plants has a beneficial effect on numerous animal groups in both disaster-affected and unaffected sites (Barton et al., 2014).

Results

Plants

Plants provided the most data with over 560 species documented in the blast area across the six time steps. Those species reside in roughly 300 genera, nearly 100 families, and almost 50 orders (Table I). Before the blast, nearly 200 genera of plants could be found in the blast zone, set in about 70 families, and over 30 orders. Currently, over 220 genera in 80 families across 45 orders can be found in the blast zone. The resetting of the Mount St. Helens ecosystem appears to have encouraged a diversity of plant life to flourish there.

Using paired t-tests, the number of species per genus, family, and order were compared to one another. In every instance, except time step six (the

Table I. This table shows the number of plant species, genera, families, and orders split by time steps. The time steps are pre-blast, 1985, 1990, 2000, 2010, and present. The final column shows the number of each group that has been gained in the present since the blast.

	Pre-Blast	1985	1990	2000	2010	Present	Total	Group Gains Since Blast*
Number of Species	328	113	141	74	159	356	569	28
Number of Genera	197	77	98	52	108	236	300	39
Number of Families	75	32	43	27	45	84	93	9
Number of Orders	35	21	25	19	25	44	47	9

* Calculated by the following equation: present - pre-blast = group gains since blast

Table II. This table shows the p-values for species richness at each time step and taxonomic level. All values are compared to their pre-blast counterparts.

	1985	1990	2000	2010	Present
Genus	7.164e-20*	2.011e-17*	1.219e-25*	2.241e-11*	0.355
Family	2.792e-9*	1.412e-8*	3.277e-9*	2.248e-7*	0.37
Order	1.14e-5*	8.57e-6*	1.01e-5*	7.36e-5*	0.512

* denotes significance

present), the p-values were significant. This was universally true across all taxonomic levels. Species richness in the present is not significantly different than it was pre-blast, but it is significantly different for all other time steps from the blast onward (Table II).

Mammals

Mammals were much less data-rich than plants with just 65 species in 22 families and seven orders (Table III). Genera-level analysis was not conducted as only one or two genera had good data. Using paired t-tests, both the family and order levels were compared to the pre-blast numbers of species at five separate time steps. Mammalian families were significantly different than the pre-blast numbers. Mammalian orders were not significantly different from the pre-blast (Table IV).

These results are likely less-robust than the plant results due to lower sample size, and the added complication of nocturnal animals like moles and bats, which are harder to observe and thus harder to obtain data for. However, the plant ecosystem is close to fully recovered while the mammals are not. Because most animals rely directly or indirectly on plant life, the plant ecosystem would need to be in place and stable for the mammalian ecosystem to stabilize.

Amphibians

The amphibians were even more data-poor than the mammals. We were able to document just 14 species in seven families across two orders living in the blast zone at any point (Table V). These numbers are similar to those documented by Swenson (2020). Before the blast, we documented a mere 12 species in five families across both orders. As with mammals, there simply needed to be more genera with more than one species to make a genera-level analysis relevant. So, only family and order-level analyses were performed.

Using paired t-tests, the time steps were compared to the first time step individually as done above. None of the results were significant (Table VI), indicating amphibian biodiversity was not affected by the Mount St. Helens eruption. Interestingly, that matches the findings of a survey of surviving vertebrates in the blast zone, which found 11 species in the blowdown zone survived the blast (Crisafulli, Swanson, and Dale, 2005). In Table V, it is interesting to note how little variance there is between pre-blast and modern species richness. This similarity may be due to incomplete data, or it may be due to amphibians surviving better in the blast zone. The improved survival could result from a water-dependent lifestyle, eggs surviving in water, or the tendency of amphibians to shelter

Table III. The table shows the number of mammal species, genera, families, and orders split by time step. The final column shows how many of each group have been lost since the blast compared to the present.

	Pre-Blast	1985	1990	2000	2010	Present	Total	Group Losses Since Blast*
Number of Species	47	26	26	8	2	19	64	-28
Number of Genera	34	21	22	8	2	17	43	-17
Number of Families	17	13	12	6	2	12	22	-5
Number of Orders	6	5	5	5	2	4	7	-2

*Calculated by the following equation: present - pre-blast = group losses since blast.

Table IV. This table shows the p-values for species richness in mammals at each time step split by taxonomic level. All are compared to the pre-blast numbers.

	1985	1990	2000	2010	Present
Genus	N/A	N/A	N/A	N/A	N/A
Family	0.056753	0.052585	0.001532	0.001086	0.020053
Order	0.079706	0.07121	0.040903	0.036595	0.07979

during the warmer parts of the day. There is also a spatial element in that, since the data was not separated by eruption zone (e.g. tephra fall, pumice, blowdown, etc.), it is possible the trend we observe is reflective of only one area of the blast zone.

Discussion

There are obvious parallels and differences between the Mount St. Helens eruption and the Flood. The Flood completely reshaped the Earth's landscape, creating new hills, valleys, rivers, canyons, and so on. Mount St. Helens did something similar, cutting the drainage of a river system and spawning a new fork of a river (Major et al., 2000). New gullies, canyons, and valleys were formed either by runoff or by direct volcanic action (Swanson and Major, 2005). In the Flood, all air-breathing, land-dwelling organisms were wiped from the face of the Earth (Genesis 7:21–22), save those in the Ark (Genesis 7:23). Mount St. Helens, while thorough, was not quite a Flood-level disaster, as organisms did survive in the blast zone (del Moral, 1981). Further, unlike the Flood, there was a surviving bank of organisms that could migrate into the blast zone to fill the void. Thus, it is likely that the Mount St. Helens ecosystem would recover more rapidly than the post-Flood world.

Drawbacks of *iNaturalist*

Due to the nature of the sampling process, some species were likely missed. The *iNaturalist* dataset in particular suffers from two significant drawbacks. First, because not all of the identifiers are trained taxonomists, there are likely false identifications mixed into the data. This issue could be mitigated if two species in the dataset are falsely identified as each other, when both are found in the study area, for example. False identifications like these may make up a sizable percentage of false identifications. Seventy-five of the 236 genera present in plants for the modern time step are represented by more than one species. The problem is likely less severe for mammals, as the lay public tends to be more familiar with them than with plants or amphibians. False identifications could skew the dataset towards a higher number of species in the present, leading to an insignificant statistical result when the true result is significant.

The second major issue with the *iNaturalist* dataset is the natural bias people have toward things they find beautiful. People are far less likely to take a picture of a grass plant than a plant with abnormal growth (cacti), pretty flowers, or trees. As an example, in the United States, there are over 24

Table V. This table shows the number of amphibian species, genera, families, and orders split by time step. The final column shows how many of each group have been gained or lost since the blast compared to the present.

	Pre-Blast	1985	1990	2000	2010	Present	Total	Group Net Since Blast*
Number of Species	12	1	1	5	7	11	14	-1
Number of Genera	8	1	1	5	6	17	9	1
Number of Families	5	1	1	4	6	7	7	2
Number of Orders	2	1	1	2	2	2	2	0

* Calculated by the following equation: present - pre-blast = group net since blast.

Table VI. This table shows the p-values for species richness in amphibians at each time-step split by taxonomic level. All are compared to the pre-blast numbers.

	1985	1990	2000	2010	Present
Genus	N/A	N/A	N/A	N/A	N/A
Family	0.071519	0.071519	0.110552	0.375818	0.735765
Order	0.361	0.361	0.258	0.677	0.874

million observations of wild plants on *iNaturalist* that are "Research Grade." Just 604,170 or roughly 1% of those observations are of grasses, despite there being roughly 11,500 species of grass, more than most other plant families (Peterson et al., 2017; *iNaturalist*, 2024). The legumes (Fabaceae), with roughly 19,500 species (Ma et al., 2021), have more than double the number of observations despite not having double the species (*iNaturalist*, 2024). This, combined with the similarity of many grasses to the layman's eye, likely created issues with the Poaceae data. The confusion between species could have inflated the number of species present in the dataset. Meanwhile, the under-observation of Poaceae species would likely deflate the number of species, leading to a roughly balanced impact.

In the mammalian dataset, the bias is evident in a different way. Nocturnal mammals, like Chiroptera, or burrowing mammals like moles, are mostly absent from the *iNaturalist* dataset as they are harder for normal people to observe. Seven members of Chiroptera are listed in the blast area before the eruption, yet none are included in the *iNaturalist* data. Chiroptera is one of the most abundant mammalian orders, yet there are just under 36,000 *iNaturalist* observations in the U.S. (Kasso and Balakrishnan, 2013; *iNaturalist*, 2024). Given that there are nearby bat populations, it seems highly unlikely that bats have not recolonized the Mount St. Helens region. It is far more likely they have simply not been recorded in the dataset due to most observers not being out at night to photograph them. The absence of Chiroptera from the *iNaturalist* dataset likely creates a more significant result than is present, making the ecosystem appear less recovered than it truly is.

Lack of Published Papers

Data paucity cannot be entirely blamed on citizen scientists, however. Despite the golden opportunity for studying ecosystem recovery that the Mount St. Helens eruption presented, surprisingly few papers were published, and they became fewer as the eruption faded further into the past. As shown in Tables I and III, species records dropped off during the 2000- and 2010-time steps, mostly due to a lack of papers on the topic. A few long-term studies were done, but only a handful of authors participated. This lack of data, particularly at the fourth- and fifth-time steps, likely influenced recovery expectations. It is possible that, were there more data from these earlier time steps, the Mount St. Helens ecosystem might have shown full recovery in an earlier time step.

Recovery

Even with the limited data availability, the Mount St. Helens ecosystem has shown a remarkable ability to recover from a devastating local catastrophe. Within 45 years, the plant ecosystem has recovered its previous richness entirely. The mammalian and amphibian ecosystems are inconclusive, due either to the lack of data or small sample size, but show promising signs. Nevertheless, Mount St. Helens cannot be considered fully recovered as a whole ecosystem. The data needed to analyze that claim is lacking, though future surveys will allow us to assess that question. However, parts of the ecosystem are fully recovered, or close to being so. This recovery shows how resilient Earth ecosystems are in the face of catastrophe. However, more research is needed on recovering areas, particularly after floods, volcanic eruptions, and earthquakes, to see if the results from Mount St. Helens hold across all such ecosystems.

Post-Flood and Mount St. Helens Blast Comparison

While post-Flood recovery is not directly comparable to Mount St. Helens, due to the survival of some organisms in the blast zone and the presence of nearby unaffected populations, some overlap still exists. It has been 45 years since the Mount St. Helens blast and the plant population is fully recovered. It would likely have taken slightly longer on the post-flood Earth, but a one-hundred-year timeline seems reasonable. The extra time allowance is conservative, assuming viable seeds did not land in certain areas and that the post-Flood climate was unstable enough to prevent habitat stabilization. It would also allow for the growth of fully mature trees from seed and the settling of plant diversity in the region. However, there would likely have been regional variations depending on climate and organism-to-organism interactions. We lack data in this study to make firm claims about fungi, but it is possible, given the abundance of dead material after the Flood, that they would have thrived. This is an excellent area of future research as more data becomes available.

Mammals, amphibians, and other land-dwelling for which we lack data in this study would likely have taken longer to reach a recovered state in the post-Flood world. This would have been partly due to smaller initial population sizes than plants and fungi. We do not know how many seeds or fungal spores survived for each fungal and plant kind, but it likely was more than the two or seven/fourteen individuals carried on the Ark. The Ark organisms also have generally lower reproductive rates than plants and fungi, which often produce thousands of seeds/spores at a time. It is reasonable to assume that the Earth's Ark organisms would have stabilized globally within a few hundred years, though with local variations depending on climate as the world entered the post-Flood Ice Age. Extinctions undoubtedly occurred during this time, but overall, the ecosystem structures likely were back to resembling pre-Flood ecosystems, at least in terms of species richness. Since we know from Scripture that Noah lived 350 years after the Flood (Genesis 9:28), by the time of his death, the Earth may have fully recovered from the catastrophic Flood. Of course, this is speculative, but it is a reasonable assumption.

Conclusion

Mount St. Helens, while a horrific catastrophe, has proven very beneficial for creationist research. Creation geology has greatly benefitted from this demonstration of how geological formations can form rapidly and not over millions of years. Recovery of the Mount St. Helens ecosystem now provides another benefit. The bleak post-Flood landscape is no obstacle to ecological recovery. Indeed, such recovery could be very rapid, within the lifetime of Noah and his family after they got off the Ark. Plants were likely close to recovering by the time Noah's grandchildren began having children. By the time of his death, Noah likely witnessed an Earth that, though topographically different, was very similar in ecosystem structure to the one God destroyed in the Flood. Plants were likely fully recovered. While we lack data for the Ark kinds, there are indications of movement toward recovery, and thus it is conceivable they were recovered, or close to recovered, by the time of Noah's death. While there are some differences, the Mount St. Helens ecosystem represents a window, however cloudy, into the recovery after the Flood.

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Age-Dating of Volcanic Rocks: A Review

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Abstract

The problems with the unproven assumptions that underpin the radioisotope age-dating methods for volcanic rocks are well-documented in the conventional (uniformitarian) literature. Assumed initial conditions are violated by inheritance from mantle and crustal sources. The required closed-radioisotope, parent-daughter systems are violated regularly by open-system behavior—contamination, loss by diffusion, and weathering. And there is good experimental evidence of past accelerated-radioisotope decay in a recent catastrophic event. Thus, the millions-of-years ages for volcanic rocks and the age-dating radioisotope methods used to obtain them are totally unreliable. However, the inflated radioisotope ages often agree with the stratigraphic and biostratigraphic positions of the volcanic strata in the rock record, which is consistent with accelerated radioisotope decay during the recent global Genesis Flood cataclysm.

Key Words: radioisotope age-dating, volcanic rocks, assumptions, inheritance, contamination, open-system behavior, accelerated decay

Introduction

The successes of the radioisotope dating methods for obtaining ages for volcanic rocks that match their presumed ages based on their relative stratigraphic and/or biostratigraphic positions in the rock record are usually trumpeted as proving those age-dating methods work. However, sometimes these standard methods have proven futile because they produce erroneous ages, as documented in the literature (Snelling, 2000). And it is precisely where the methods fail that the unproven assumptions behind the methods are exposed. How serious this problem may really be is hard to gauge or quantify because it would seem that not all discrepant results are published, for obvious reasons. Nevertheless, if we use the Dalrymple (1969) study as a guide, he reported that about one-quarter of his results were anomalous (see below). At least he knew which samples gave anomalous results, but in other studies using other methods there are not always clear indications of which results might be anomalous apart from them not matching the expected target. This then could still be quite a serious widespread problem. That then raises the question—if these methods fail when the correct ages of the rocks are known, how can we trust these methods on rocks of unknown ages? After all, such failures are likely

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to be systematic, so that even when the methods provide ages compatible with the presumed ages, the compatibility may likewise be flawed.

The May 18,1980, volcanic eruption of Mount St. Helens may not have been the largest or most devastating historic eruption, but it was one of the most geologically significant. It provided a natural laboratory for geologists to witness the results of catastrophic geological processes.

Among the geological surprises was further confirmation that volcanic rocks cannot be accurately age-dated by radioisotope methods. Subsequent to the May 18, 1980, eruption, a new lava dome grew within the blasted-out crater. Austin (1996) collected a sample from it and submitted it to a recognized commercial laboratory for K-Ar dating. The whole-rock dacite sample yielded a K-Ar age of 350,000 years, while mineral concentrates separated from it yielded K-Ar ages up to 2.8 ± 0.6 Ma (million years). It was concluded that excess argon had been inherited from the volcanic gases trapped in the lava as it cooled and crystallized.

Stung by this result being used by a creationist geologist to discredit the K-Ar radioisotope dating method, opponents such as G. Brent Dalrymple (of the UC Berkeley Geochronology Laboratory) were vociferous in their efforts to accuse Steve Austin of incompetence and misapplying the K-Ar method to such a recent volcanic rock. However, the irony is that Dalrymple himself years before used the K-Ar method to date recent volcanic rocks (Dalrymple, 1969). Indeed, numerous other workers have also found the same problem that recent volcanic rocks inherit excess argon when they crystallize.

K-Ar Dating of Volcanic Rocks

Snelling (2000) provided a detailed overview with extensive documentation of this and other problems in age-dating volcanic rocks with the K-Ar method.

Critical to this method is the assumption that there was no radiogenic ^{40}Ar* (the asterisk * denoting radiogenic ^{40}Ar as distinct from non-radiogenic ^{40}Ar) in rocks such as basalts when they formed, which is usually stated as being self-evident. For example, Geyh and Schleicher (1990, p.56) state:

> What is special about the K-Ar method is that the daughter nuclide is a noble gas, which is not normally incorporated into minerals and is not bound in the mineral in which it is found.

Similarly, Dalrymple and Lanphere (1969, p.46) state:

> ...a silicate melt will not usually retain the ^{40}Ar that is produced, and thus the potassium-argon clock is not "set" until the mineral solidifies and cools sufficiently to allow the ^{40}Ar to accumulate in the mineral lattice.

And Dalrymple (1991, p.91) argued strongly:

> The K-Ar method is the only decay scheme that can be used with little or no concern for the presence of the daughter isotope. This is because ^{40}Ar is an inert gas that does not combine chemically with any other element and so escapes easily from rocks when they are heated. Thus, while a rock is molten, the ^{40}Ar escapes from the liquid.

Excess ^{40}Ar

However, that dogmatic statement is incompatible with Dalrymple's own earlier work on 26 historic subaerial lava flows, about 25% of which had non-zero concentrations of ^{40}Ar* (that is, excess ^{40}Ar*) in violation of that key assumption of the K-Ar dating method (Dalrymple, 1969). The amounts of ^{40}Ar* found in these historic lava flows were equivalent to the K-Ar ages listed in Table I. Furthermore, there are numerous other reported examples of excess ^{40}Ar* in recent or young volcanic rocks equivalent to the excessively old K-Ar ages listed in Table II (Snelling, 2000).

Measurements of excess ^{40}Ar* in lavas have been commonly reported. Fisher (1970) investigated submarine

Table I. Anomalous K-Ar ages for historic lavas calculated from their K-Ar analyses [Dalrymple, 1969].

Rock/Mineral Location	Historic Date	K-Ar Ages
Hualalai basalt, Hawaii	AD 1800–1801	1.6 ± 0.16 Ma and 1.41 ± 0.08 Ma
Mt. Etna basalt, Sicily	122 BC	0.25 ± 0.08 Ma
Mt. Etna basalt, Sicily	AD 1972	0.35 ± 0.14 Ma
Mt. Lasson plagioclase, California	AD 1915	0.11 ± 0.03 Ma
Sunset Crater basalt, Arizona	AD 1064–1065	0.27 ± 0.09 Ma and 0.25 ± 0.15 Ma

basalt from a Pacific seamount and found "the largest amounts of excess ^{4}He and ^{40}Ar ever recorded" (at that time). McDougall (1971) found "extraneous radiogenic argon present in three of the groups of basalt flows" on the young volcanic island of Reunion in the Indian Ocean. Significant quantities of excess ^{40}Ar* have also been recorded in submarine basalts, basaltic glasses and olivine phenocrysts from the currently active Hawaiian volcanoes, Loihi Seamount and Kilauea, as well as on the flanks of Mauna Loa and Hualalai volcanoes, also part of the main island of Hawaii (Honda et al., 1993; Valbracht et al., 1996b), and in samples from the Mid-Atlantic Ridge, East Pacific Rise, Red Sea, Galapagos Islands, McDonald Seamount, and Manus Basin (Staudacher et al., 1989; Marty and Humbert, 1997). Patterson et al. (1990) claimed that some of the initial Loihi analytical results were due to atmospheric contamination of the magma either during intrusion or eruption, but subsequent work (Honda et al., 1993; Valbracht et al., 1996b) confirmed that the excess ^{40}Ar* was not from atmospheric contamination at all.

In Austin's (1996) investigation of the 1986 dacite lava flow from the post-October 26, 1980, lava dome within the Mount St. Helens crater, he established that the 10-year-old dacite (when dated in 1996) yielded a whole-rock K-Ar model age of 0.35 ± 0.05 Ma due to excess ^{40}Ar* in the rock. He then produced concentrates of the constituent minerals, which yielded anomalous K-Ar model ages of 0.34 ± 0.06 Ma (plagioclase), 0.9 ± 0.2 Ma (hornblende), 1.7 ± 0.3 Ma (pyroxene), and 2.8 ± 0.6 Ma (pyroxene ultra-concentrate). While these mineral concentrates were not ultra-pure, given the fine-grained glass in the groundmass and some Fe-Ti oxides, it is nonetheless evident that the excess ^{40}Ar* responsible for the anomalous K-Ar ages was retained within the different constituent minerals in different amounts. Furthermore, the whole-rock age was very similar to the age of the plagioclase concentrate because plagioclase is the dominant constituent of the dacite.

Similarly, Snelling (1998) reported that andesite flows on New Zealand's newest and most active volcano, Mt. Ngauruhoe in the Taupo Volcanic Zone, which produced andesite flows in 1949 and 1954, and avalanche deposits in 1975, yielded K-Ar model ages for five of these flows and deposits from <0.27 Ma to 3.5 ± 0.2 Ma. These dates could not be reproduced, even

Table II. Anomalous K-Ar ages for lavas with historic or expected recent ages [sources in Snelling, 2000].

Rock/Mineral Location	Historic/Expected Date	K-Ar Ages
Akka Waterfall Flow, Hawaii	Pleistocene	32.3 ± 7.2 Ma
Kilauea Iki basalt, Hawaii	AD 1959	8.5 ± 6.8 Ma
Mt. Stromboli, volcanic bomb	AD 1963	2.4 ± 2 Ma
Mt. Etna basalt, Sicily	AD 1964	0.7 ± 0.01 Ma
Medicine Lake Highlands obsidian, California	<500 years old	12.6 ± 4.5 Ma
Hualalai basalt, Hawaii	AD 1800–1801	22.8 ± 16.5 Ma
Alkali basalt plug, Benue, Nigeria	<30 Ma	95 Ma
Olivine basalt, Nathan Hills, Antarctica	<3 Ma	18.0 ± 0.7 Ma
Anorthoclase, Mt. Erebus, Antarctica	AD 1984	0.64 ± 0.03 Ma
Kilauea basalt, Hawaii	<200 years old	21.8 Ma
Kilauea basalt, Hawaii	<1000 years old	42.9 ± 4.2 Ma and 30.3 ± 3.3 Ma
East Pacific Rise basalt	<1 Ma	690 ± 7 Ma
Seamount basalt near East Pacific Rise	<2.5 Ma	580 ± 10 Ma and 700 ± 150 Ma
East Pacific Rise basalt	<0.6 Ma	24.2 ± 1.0 Ma

from splits of the same samples from the same flow, the explanation being variations in excess ^{40}Ar* content.

That the excess ^{40}Ar* can be occluded in the minerals within lava flows, rather than between the mineral grains, has been established by others also. Laughlin et al. (1994) found that the olivine, pyroxene, and plagioclase in Quaternary basalts of the Zuni-Bandera volcanic field of New Mexico contained very significant quantities of excess ^{40}Ar*, as did the olivine and clinopyroxene phenocrysts in Quaternary flows from New Zealand volcanoes (Patterson et al., 1994). Similarly, Poths et al. (1993) separated olivine and clinopyroxene phenocrysts from young basalts from New Mexico and Nevada and then measured "ubiquitous excess argon" in them. Damon et al. (1967) reported several instances of phenocrysts with K-Ar ages 1–7 million years greater than that of the whole rocks, and one K-Ar date for olivine phenocrysts of greater than 110 Ma in a recent (<13,000-year-old) basalt. Damon et al. (1967) thus suggested that large phenocrysts in volcanic rocks contain the excess ^{40}Ar* because their size prevents them from completely degassing before the flows cool, but Dalrymple (1969) concluded that there does not appear to be any correlation of excess ^{40}Ar* with large phenocrysts or with any other petrographic parameter.

Thus, most investigators have concluded that the excess ^{40}Ar* had to obviously be present in the molten lavas when they were extruded, which then did not completely degas as they cooled, the excess ^{40}Ar* becoming trapped in constituent minerals, and in some instances, the rock fabrics themselves. Laboratory experiments have tested the solubility of argon in synthetic basalt melts and their constituent minerals, with olivine retaining 0.34 ppm ^{40}Ar* (Broadhurst et al., 1990, 1992). It was concluded that the argon is held primarily in lattice vacancy defects within minerals.

However, from whence came the excess ^{40}Ar*, because it is argon which cannot be attributed to atmospheric contamination or in situ radioactive decay of ^{40}K? It is not simply "magmatic" argon. Funkhouser and Naughton (1968) found that the excess ^{40}Ar* in the 1800–1801 Hualalai flow, Hawaii, resided in fluid and gaseous inclusions in olivine, plagioclase, and pyroxene in ultramafic xenoliths in the basalt, and was sufficient to yield ages of 2.6 Ma to 2960 Ma. Thus, since the ultramafic xenoliths and the basaltic magmas came from the mantle, the excess ^{40}Ar* must initially reside there, to be transported to the Earth's surface in the magmas.

Many studies confirm the mantle source of excess ^{40}Ar*. Hawaiian volcanism is typically cited as resulting from a mantle plume. Most investigators now concede that excess ^{40}Ar* in the lavas, including those from the active Loihi and Kilauea volcanoes, is indicative of the mantle source area from which the magmas came (Patterson et al., 1990; Honda et al., 1993). Considerable excess ^{40}Ar* measured in ultramafic mantle xenoliths from Kerguelen Archipelago in the southern Indian Ocean likewise is regarded as the mantle source signature of hotspot volcanism (Valbracht et al., 1996a). Indeed, data from single vesicles in mid-ocean ridge basalt samples dredged from the North Atlantic suggest the excess ^{40}Ar in the upper mantle may be almost double previous estimates, that is, almost 150 times more than the atmospheric content (relative to Ar) (Moreira et al., 1998). Another study on the same samples indicates the upper mantle content of Ar could be even ten times higher (Burnard et al., 1997).

The key issue is still where this excess ^{40}Ar has come from, and whether it has been derived from radioactive decay of ^{40}K. One possibility is that the excess ^{40}Ar can be accounted for by radioactive decay during long-term residence of magmas in chambers before eruption. Esser et al. (1997) discounted this option for the Mt. Erebus anorthoclase phenocrysts. Dalrymple (1969) found that whereas the Mt. Lassen (1915) plagioclase phenocrysts yielded excess ^{40}Ar and an anomalous K-Ar model age, a plagioclase from the 1964 eruption of Surtsey only had argon whose isotopic composition matched that of air. Surtsey is an island off the southern coast of Iceland that formed in a volcanic eruption that began in 1963 and lasted until 1967 when the island reached its maximum size of 2.7 km^2 (1.0 sq. mi.) (Decker and Decker, 1997). Because phenocrysts usually crystallize from lavas after eruption, they may arbitrarily trap excess ^{40}Ar during lava cooling, ^{40}Ar that will thus not be from in situ ^{40}K radioactive decay in the magma's mantle source.

Indeed, diamonds and their micro-inclusions are a means of sampling the mantle because they are thermodynamically stable at the depths greater than 150 km where they formed, apparently in the Archean (Kirkley et al., 1992). When Zashu et al. (1986) obtained a K-Ar isochron age of 6.0 ± 0.3 Ga for ten Zaire diamonds, it was obvious excess ^{40}Ar* in the mantle was responsible, because the diamonds could not be older than the Earth itself. In a follow-up study Podosek et al. (1988) found that the ^{40}K present in these diamonds was in normal isotopic abundance, so the erroneous age had to be due to excess ^{40}Ar* not generated in situ but inherited or in trapped fluids from the mantle reservoir where the diamonds formed. Furthermore, Johnson et al. (2000) analyzed fluid inclusions in diamonds and found extremely high ^{40}Ar/^{36}Ar ratios and ^{40}Ar* poorly correlated with K indicative of mantle-derived excess ^{40}Ar* not produced by in situ decay of ^{40}K. Clearly, excess ^{40}Ar* is abundant in the mantle and can easily be transported up into the crust.

Thus, excess ^{40}Ar* migrating from the mantle is found in crustal rocks and minerals. Amounts of excess ^{40}Ar* in some CO_2-rich natural gas wells were found to exceed those in mantle-derived mid-ocean ridge basalts (Staudacher, 1987; Staudacher et al., 1989; Burnard et al., 1997; Moreira et al., 1998). It was also noted that the quantities of excess ^{40}Ar* in the continental crust can thus be as much as five times that found in mantle-derived, mid-ocean ridge basalts, strongly suggesting that excess ^{40}Ar* in crustal rocks and minerals could well be the norm rather than the exception.

Similarly, as Dalrymple (1991) commented, if a rock is heated or melted within the continental crust, then some or all the ^{40}Ar* may escape and migrate in the crust to be incorporated in other rocks and minerals as excess ^{40}Ar*. Thus, excess ^{40}Ar* has been recorded in many minerals in crustal rocks, some of which contain no ^{40}K, such as quartz, plagioclase, pyroxene, hornblende, biotite, olivine, beryl, cordierite, tourmaline, albite and spodumene in pegmatites, metamorphic rocks, and lavas (Damon and Kulp, 1958; Funkhouser et al., 1966; Laughlin, 1969).

Melton and Giardini (1986) found an ^{40}Ar/^{36}Ar value of 189 compared to a ratio of 294 for atmospheric argon in a diamond. Also, Melton and Giardini (1982) discussed models for the changes in Ar isotope contents of the mantle and the atmosphere over Earth history. Ozima (1975) gave a discussion of similar questions.

This crustal migration of ^{40}Ar* is thus known to cause grave problems in geochronology studies. For example, in the Precambrian Musgrave Block, northern South Australia, Webb (1985) found a wide scatter of K-Ar mineral ages ranging from 343 Ma to 4493 Ma due to inherited excess ^{40}Ar*, so that no meaningful interpretation could be drawn from the rocks. He concluded that the mafic magmas that formed the diabase dikes which gave anomalous ages "probably formed in or passed through zones containing a high partial pressure of ^{40}Ar*, permitting inclusion of some of the gas in the crystallizing minerals."

All this evidence clearly shows that excess ^{40}Ar* is ubiquitous in volcanic rocks when they cool and crystallize, and that the excess ^{40}Ar* was inherited from the mantle source areas of the magmas. This is not only true for recent and young volcanics, but for ancient volcanics such as the Middle Proterozoic Cardenas Basalt of eastern Grand Canyon (Austin and Snelling, 1998). The ^{40}Ar* intercept of their K-Ar isochron indicated there was some initial (inherited excess) ^{40}Ar* in those lava flows when they were extruded. Thus, in both the mantle and the crust, it has been repeatedly demonstrated that this ^{40}Ar predominantly represents primordial argon that is not derived from in situ radioactive decay of ^{40}K and thus has no age significance.

^{40}Ar Loss

While it is so evident that excess ^{40}Ar*, whether primordial or inherited, is a significant problem for age-dating of volcanic rocks, that is not the only encountered problem. For the K-Ar radioisotope method to work successfully, the ^{40}Ar* produced by in situ radioisotope decay of ^{40}K after the volcanic rocks are extruded has to be retained within them. Yet ^{40}Ar* loss from minerals is known to be a persistent problem. Because Ar is a noble (non-reactive) gas it does not form bonds with other atoms in crystal lattices of minerals, so no mineral phase preferentially takes up Ar (Dalrymple, 1991, p. 91). Rather, it is claimed that Ar can be readily lost from the minerals such as feldspar in volcanic rocks where it is produced. Ar also displays limited partition into fluids.

Faure (1986, p. 69) lists the causes in volcanic rocks to which Ar loss can be attributed:

- inability of mineral lattices to retain Ar even at low temperatures and atmospheric pressure,
- either partial or complete melting of rocks followed by crystallization of new minerals from the resulting melt (lava),
- increase in temperature from deep burial or contact metamorphism causing Ar loss from most minerals without producing any other chemical or physical changes in the rocks,
- metamorphism at elevated temperatures and pressures of volcanic rocks resulting in complete or partial Ar loss depending on the temperature and the duration of the event,
- chemical weathering and alteration by aqueous fluids, leading not only to Ar loss but also to changes in the K content of minerals,
- solution and redeposition of water-soluble minerals, and
- mechanical breakdown of minerals, radiation damage, and shock waves (even excessive grinding of rocks during their preparation for dating).

However, such explanations may often be resorted to in order to resolve conflicts between K-Ar dating results and expectations based on the evolutionary timescale, rather than being based on substantial experimental verification. Nevertheless, Ar is soluble in water (Mazor and Fournier, 1973; Mauger, 1977) and has a similar molecular diameter to water, so it can be removed from minerals and rocks by ground and thermal waters.

A very good demonstration of apparent ^{40}Ar* loss from different minerals in a thermal event is provided in the contact metamorphic zone associated with the Eldora granitic stock in the Colorado Front Range (Hart, 1964). The 54-Ma stock was intruded into Precambrian metamorphic rocks regarded as approximately 1350 Ma. It was found the K-Ar ages of biotite, hornblende, and K-feldspar in the host metamorphic rocks in close proximity to the intrusive contact decreased as a result of increasing losses of ^{40}Ar*, based on their presumed evolutionary age (Figure 1). That is, the fraction of ^{40}Ar* lost from each of the minerals decreased as a function of increasing distance from the contact and reflected the differing retentivities of these minerals for ^{40}Ar*. Whereas the coarse biotite lost almost all of its ^{40}Ar* at a distance of about 100 m (~300 ft.) from the contact, the effects of ^{40}Ar* loss could be traced for more than 2 km (1.2 miles) beyond that distance and the biotite K-Ar dates finally stabilized at a distance of about 4.25 km (2.6 miles) from the contact. The K-feldspar K-Ar dates increased somewhat erratically away from the contact and showed the effects of a substantial fraction of ^{40}Ar* loss even at a distance of almost 7 km (4.3 miles) from the contact. That distance is unlikely to be within the thermal aureole of the granitic stock but reflects the widely accepted view that K-feldspars may lose Ar by diffusion even at ambient temperatures (Dickin, 2005).

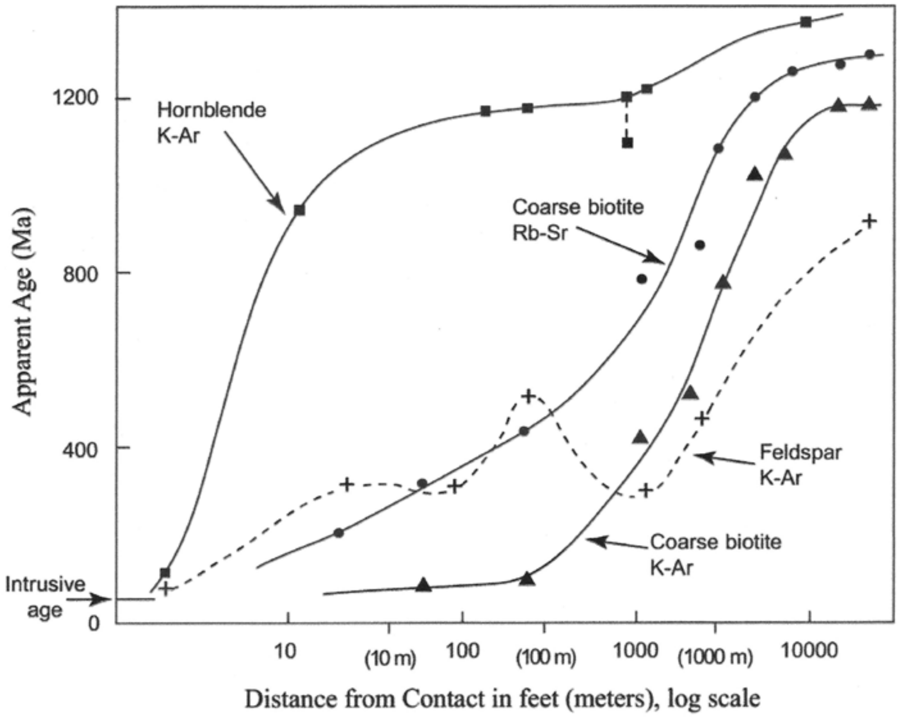

Figure 1. Plot of apparent mineral ages in Precambrian metasediments and metavolcanics against outward distance from the contact of the Tertiary Eldora granite stock, Colorado [after Hart, 1964].

It has been found that when a K-bearing mineral is heated, the ^{40}Ar* that has accumulated in it escapes by diffusion into intergranular space (Dalrymple, 1991, pp. 91, 115). Harrison (1981) experimentally measured the ^{40}Ar* loss from two compositionally contrasting hornblendes to determine the rate of ^{40}Ar* diffusion. To be assured that the ^{40}Ar* was released by diffusion, he heated the hornblendes under hydrothermal conditions at different temperatures and calculated the diffusion coefficients for Ar from the fraction of ^{40}Ar* released as a function of temperature. Harrison et al. (1985) conducted similar experiments to measure ^{40}Ar* loss from hydrothermally treated biotite and found that ^{40}Ar diffusivity in biotites is strongly dependent on the Fe/Mg ratio. They thus predicted that Fe-rich biotite was significantly less retentive of ^{40}Ar* than biotites of intermediate Fe/Mg compositions, a prediction confirmed by Grove and Harrison (1996). However, Fechtig and Kalbitzer (1966) found from extensive experimentation that diffusion at room temperatures is always so small that no appreciable Ar losses occur.

Nevertheless, K-Ar dating of ancient lava flows confirms that while they may have inherited excess ^{40}Ar* when they cooled and crystallized, with time they exhibit a net ^{40}Ar* loss. Austin and Snelling (1998) found that the Middle Proterozoic Cardenas Basalt of eastern Grand Canyon yielded a K-Ar isochron age of only 516 Ma, which is the same as the conventional Cambrian age of the overlying sedimentary strata, but less than half the published Rb-Sr isochron age of 1100 Ma (Larsen et al., 1994). They rejected that K-Ar isochron age, citing the conventional explanation was resetting of the K-Ar age due to Ar leakage and loss in the time since these lava flows were buried under other rock layers.

Similarly, Mankinen and Dalrymple (1972) rejected a 1.6 ± 0.1 Ma K-Ar date for the glassy matrix of a basalt because its plagioclase phenocrysts yielded a K-Ar age of 7.4 ± 0.2 Ma. Even though the glassy matrix constituted 75% of the rock and also contained plagioclase laths, and the rock's K content is almost entirely concentrated in the glass, which was described as unaltered, this age discrepancy was blamed on ^{40}Ar* loss from the glass. In contrast, Evernden et al. (1964) analyzed several devitrified volcanic glasses of "known" conventional ages and all yielded K-Ar ages that were too young, some being virtually zero ages, so they attributed this to ^{40}Ar* loss due to devitrification. So, how could ^{40}Ar* be equally lost from unaltered glass and devitrified (altered) glass?

The reality is that there is a steady loss of ^{40}Ar* from crustal rocks to the atmosphere (Drescher et al., 1998), which is a result of degassing of primordial ^{40}Ar and ^{40}Ar* from radioactive decay of ^{40}K in the mantle and crust. Although it has been amply demonstrated that this ^{40}Ar* flux produces a buildup of excess ^{40}Ar* in both mantle-derived volcanic and crustal rocks, ^{40}Ar* loss can clearly be a problem locally and regionally, resulting in anomalous K-Ar ages. Therefore, when the ^{40}Ar* contents of volcanic rocks and their minerals are measured, there is no way of determining categorically whether there has been ^{40}Ar* loss, even when the calculated ages are compatible with other radioactive dating systems or the expected conventional ages. This renders K-Ar dating as questionable at best.

Ar-Ar Dating of Volcanic Rocks

The Ar-Ar method is now routinely used, often in preference to the K-Ar method, and depends on the diffusion of ^{40}Ar* as minerals are heated in the dating laboratory. However, the method also depends on the irradiation of the ^{40}K in the rock and its minerals to convert it to ^{39}Ar. The ^{40}Ar/^{39}Ar ratios can then be more easily measured in single analyses in a mass spectrometer, rather than the ^{40}K and ^{40}Ar* contents being analyzed by separate techniques. But since the irradiation of the samples to convert the ^{40}K to ^{39}Ar is undertaken in nuclear reactors, there are fluctuations in the neutron fluxes of different reactors during the procedure. Thus, samples of known ages called fluence monitors are added to every batch of samples of unknown ages and those known ages are then used in the equation to solve for the ages of the unknown samples. Therefore, the Ar-Ar dating method depends on the accuracy of whatever radioisotope methods were used to establish the known ages of the fluence monitors. So, it is not an independent dating method, as is often claimed, nor is it any more reliable that the methods used to date the known ages of the fluence monitors. Ironically, for the dating of young volcanic rocks, the known ages of the fluence monitors have usually been dated by the K-Ar method!

Overman (2010) evaluated the Ar-Ar method and also exposed these and other problems. Among them he discussed how Dalrymple et al. (1993) performed an ^{40}Ar-^{39}Ar analysis of the Beloc Formation, Haiti, and pointed out some inconsistencies in the equations they used in this method.

Thus, the Ar-Ar method also suffers from the same problems as the K-Ar method, namely, excess ^{40}Ar* and ^{40}Ar* loss. So, the same examples of these issues from the conventional literature with respect to the failures of the K-Ar method also apply to the Ar-Ar method. However, a few additional examples confirm this.

The same ten Zaire diamonds for which Zashu et al. (1986) obtained a K-Ar isochron age of 6.0 ± 0.3 Ga (billion years), Ozima et al. (1989) found they produced an Ar/Ar age spectra yielding a ~5.7 Ga isochron. They also discovered that just as there was an excellent correlation between those diamonds' K contents and ^{40}Ar/^{36}Ar ratios, there was a correlation between their Cl contents and ^{40}Ar. They thus concluded that the ^{40}Ar was an excess component which has no age significance and is found in tiny inclusions of mantle-derived fluid.

Pickles et al. (1997) obtained 128 isotopic Ar analyses from ten profiles across biotite grains in an amphibolite-granulite facies metamorphic rock and ^{40}Ar-^{39}Ar ages within individual grains ranged from 161 to 515 Ma (Figure 2). They concluded that these observations could not be solely due to radiogenic buildup of ^{40}Ar* but must be due to incorporation by diffusion into the grains of excess ^{40}Ar* from an external source, namely, excess ^{40}Ar* from the mantle and in other crustal rocks and minerals.

In a detailed ^{40}Ar-^{39}Ar dating study of high-grade metamorphic rocks in the Broken Hill region of NSW (Australia), Harrison and McDougall (1981) found evidence of widely distributed excess ^{40}Ar*. Step-heating ^{40}Ar-^{39}Ar age spectra for plagioclases in mafic granulites (metamorphosed volcanic rocks) yielded unacceptable ages of up to 9.588 Ga, produced by excess ^{40}Ar* released at temperatures of 350–650°C and/or 930–1380°C. They suggested that the excess ^{40}Ar* is held in sites within the mineral lattice, such as structural holes, edge dislocations, and lattice vacancies. Thus, their study showed that at crustal temperatures, excess ^{40}Ar* will always be retained in those trapping sites, thus rendering ^{40}Ar-^{39}Ar dating questionable.

Rb-Sr Dating of Volcanic Rocks

The Rb-Sr isochron method is widely used for age dating, because most crustal rocks and minerals within them contain sufficient Rb and Sr (10–1000 ppm) to make their chemical separation and then mass spectrometry relatively straightforward. However, the results of Rb-Sr geochronology have not always been easy to interpret because it is claimed that both Rb and

Sr are mobile elements, so that the isotopic system may be readily disturbed either by influx of fluids or by a later thermal event (Rollinson, 1993, pp. 226–227; Rollinson and Pease, 2021, p. 190). On the other hand, Hanson and Gast (1967) stated that significantly no one had been able to thermally induce radiogenic ^{87}Sr to leave host minerals commensurable with ^{40}Ar loss under reasonable geological conditions, even though it was not uncommon to find biotites which had lost both ^{40}Ar and ^{87}Sr due to a thermal event.

Indeed, the previously cited contact metamorphic zone associated with the Eldora granitic stock in the Colorado Front Range is a classic example (Hart, 1964). The 54-Ma stock was intruded into Precambrian metamorphic rocks regarded as approximately 1350 Ma. The coarse biotites in the Precambrian amphibolites and schists showed even greater disturbance of the Rb-Sr system than the K-Ar system (Figure 1). Hart (1964) calculated that the coarse biotite only 20 feet (~6 m) from the contact with the granitic stock had lost 88% of its radiogenic ^{87}Sr, while the loss at 14,100 feet (~4.3 km) was essentially zero.

Similarly, Hansen and Gast (1967) investigated the effects of thermal metamorphism on Rb-Sr ages of biotite, muscovite, and K-feldspar in a granitic stock in Minnesota near its contact with an intrusive gabbro and on Rb-Sr ages of biotite in an amphibolite in Wyoming intruded by a diabase dike. The apparent loss of ^{87}Sr from biotite had occurred at moderate temperatures near and out to 20 m from the Wyoming dike, but near and out to 5 km from the Minnesota gabbro.

Furthermore, Patel et al. (1999) found contrasting responses in the Rb-Sr radioisotope system between regional and contact metamorphism. Whereas the Rb-Sr isotopic data required that ^{87}Sr was redistributed during regional metamorphism on a scale of at least tens of meters, during subsequent contact metamorphism at an apparent higher temperature isotopic mobility was restricted to a centimeter-scale or less. They concluded that the regional metamorphism involved fluid transport which facilitated Sr isotopic resetting, whereas the contact metamorphism occurred in a relatively dry environment in which isotopic mobility was restricted. However, fluids facilitate isotopic mobility at all observational scales, particularly when their chemistry and temperature make them more reactive.

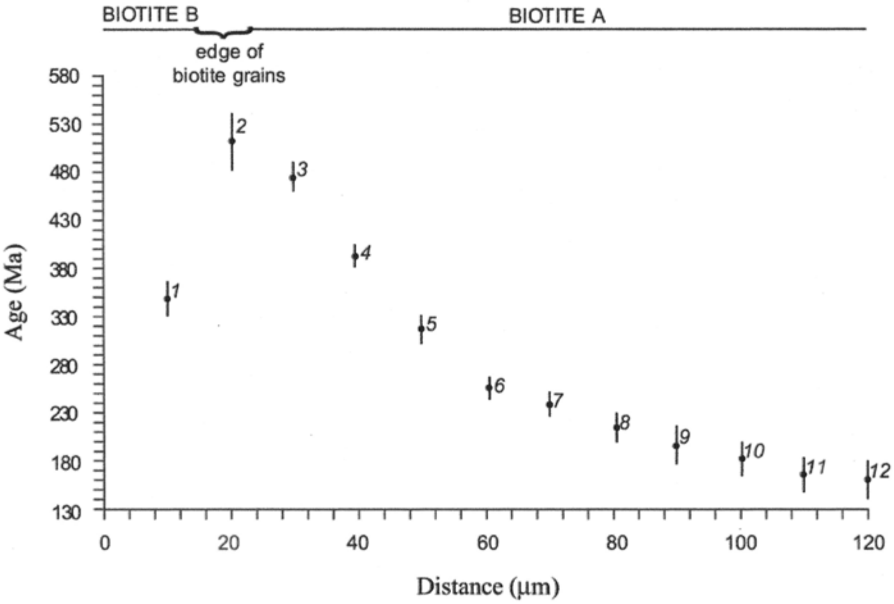

Figure 2. Apparent age versus distance profile across adjacent biotite grains in an amphibolite-granulite facies metamorphic rock from the Italian Alps [after Pickles et al., 1997—their profile 8 across sample 85370]. This high spatial resolution profile is along a "trench" produced by the beam from an ultraviolet laser ablation microprobe which is parallel to the biotite cleavage and perpendicular to the grain boundary. Apparent ages range from 515 ± 27 Ma at the edge of biotite A to 161 ± 19 Ma 100 μm in from the edge of biotite A. The high apparent ages at the grain boundary cannot be attributed to alteration because scanning electron microscope (SEM) images discount it.

Consequently, the Rb-Sr method lost credibility in the 1980s as evidence of open-system behavior mounted (Dickin, 2005, p. 51). For example, Rb-Sr isochrons in metamorphic terrains yielded good linear arrays whose ages were meaningless. And Rb-Sr systems appeared disturbed and reset to give good-fit secondary isochrons even by relatively low-grade metamorphism when there was little field evidence and only relatively minor mineralogical alteration (Zheng, 1989).

Open-system behavior can occur at even lower grades of metamorphism in fine-grained, acidic volcanic rocks (i.e., silica-rich, "felsic" rocks). Such units are attractive for conventional "absolute" dating of the stratigraphic record because they are conformable with the enclosing sedimentary strata. Experience has shown they are particularly susceptible to radiogenic ^{87}Sr loss, because the mobility of ^{87}Sr is facilitated by its formation in situ into non-lattice positions, allowing the ^{87}Sr to easily migrate during any subsequent metamorphism. Thus, when the Stockdale rhyolite, England, yielded a 16-point Rb-Sr isochron age that was inconsistent with its presumed age based on biostratigraphy and other dating methods, it was argued that the whole unit had probably been disturbed by a postulated hydrothermal event after its extrusion and subsequent burial (Compston et al., 1982).

In reality, few mineral-rock systems are perfectly homogenized during any metamorphism (Zheng, 1989), the open-system Rb-Sr systematics in numerous environments discrediting Rb-Sr isochron dating (Dickin, 2005, pp. 48–52). Gain or loss of Rb and Sr from rocks can be so regular that a linear array can be produced on a conventional isochron diagram and biased isochron results give spurious ages and initial ^{87}Sr/^{86}Sr ratio estimates (Zheng, 1989). Zheng (1989) concluded that:

> As it is impossible to distinguish a valid isochron from an apparent isochron in the light of Rb-Sr isotopic data alone, caution must be taken in explaining the Rb-Sr isochron age of any geological system…an observed isochron does not certainly define a valid age information for a geological system, even if a goodness of fit of the experimental data points is obtained in plotting ^{87}Sr/^{86}Sr vs. ^{87}Rb/^{86}Sr. This problem cannot be overlooked in evaluating the numerical timescale.

Indeed, the Rb-Sr dating method relies on assuming samples from a cogenetic rock unit are the same age, have the same initial ^{87}Sr/^{86}Sr ratio, and acted as a closed system. The goodness of fit of the analytical data points in the plot of ^{87}Sr/^{86}Sr versus ^{87}Rb/^{86}Sr served as a check on these assumptions. However, when applied to an increasing number of geological situations, it soon became apparent that excellent-fitting linear relationships between ^{87}Sr/^{86}Sr and ^{87}Rb/^{86}Sr ratios could yield anomalous isochrons with no distinct geological or age meaning, as recognized by Zheng (1989).

For example, Sun and Hansen (1975) found that the Rb-Sr data for fourteen different, recently-erupted ocean island basalts when plotted on an isochron yielded a positive correlation with an ~2 Ga age. They also found that the basalts on individual ocean islands sometimes also yielded false isochrons, which they attributed to the Rb/Sr isotopic composition of the heterogeneous mantle sources of the magmas. Thus, Brooks et al. (1976a) used the term "mantle isochrons" for these apparent ages. And it is now well-known that basalt magmas will inherit the isotopic composition of their mantle source (Dickin, 2005, pp. 45–46).

Brooks et al. (1976b) extended the concept of mantle isochrons to continental igneous rocks in their Rb/Sr isotopic study of thirty "ancient" continental volcanic and plutonic rock suites. The resultant data for each of the rock suites formed pseudo-isochrons which they rejected as mixing lines produced by crustal contamination of the mantle-derived basalt magmas, instead interpreting them as representing the Rb/Sr isotopic chemistry of domains in the subcontinental lithosphere. Austin (1994) confirmed this when he found the Rb/Sr isotopic data for the recent Uinkaret Plateau lava flows in western Grand Canyon yielded an Rb-Sr isochron age of ~1.1 Ga, identical to the conventionally established Rb-Sr isochron age for the Precambrian Cardenas Basalt in eastern Grand Canyon (Larson et al., 1994). Both the recent and "ancient" basalt lavas had thus been derived from the same mantle source with the same Rb/Sr chemistry, and not age.

Another example of correlated ^{87}Sr/^{86}Sr and ^{87}Rb/^{86}Sr ratios was reported by Bell and Powell (1969) for lava flows in two volcanic centers 160 km apart in east Africa. These lavas are known to be quite young; some even having erupted in historic times. However, their ^{87}Sr/^{86}Sr ratios correlated positively with their ^{87}Rb/^{86}Sr ratios, yielding an isochron age of 773 Ma for these young lavas 160 km apart. This fictitious age was thus interpreted as due to a mixing process, and not due to radioactive decay of ^{87}Rb in the rocks after their formation. Snelling (2003) found there had been a similar isotopic mixing process as basalt magma was contaminated by wall-rocks on its passage from the mantle wedge source under New Zealand to erupt recently as andesite lava flows at Mt. Ngauruhoe.

Faure and Powell (1972, pp. 36–41) demonstrated that many apparently cogenetic suites of both oceanic and continental volcanic rocks have significant within-suite variations in their initial ^{87}Sr/^{86}Sr ratios, which violates a key assumption of Rb-Sr age dating. They suggested these variations were caused by either differences in the initial ^{87}Sr/^{86}Sr ratios of the source regions in the upper mantle and lower crust, or variable contamination of their parent magmas via bulk assimilation, wall-rock reactions, selective migration of radiogenic ^{87}Sr, and/or isotopic exchange and equilibration.

Thus, Cortini and Hermes (1981) documented variations in the initial ^{87}Sr/^{86}Sr ratios for suites of young lavas from a single volcano, demonstrating that the assumption of a well-defined initial ^{87}Sr/^{86}Sr ratio for many suites of volcanic rocks is violated. Obviously, the state of the Rb-Sr system at the time of formation of a rock is of crucial importance in understanding the meaning of an isochron. Yet even samples that do not have identical ages and initial ^{87}Sr/^{86}Sr ratios can be fitted to isochrons (Köhler and Müller-Sohnius, 1980; Haack et al., 1982). Furthermore, the interpretation of Rb-Sr isotope data is influenced by factors external to the actual Rb-Sr radioisotope system, such as the rotation of an isochron to describe the perceived distortion of the Rb-Sr system in German volcanics due to presumed post-magmatic processes (Schleicher et al., 1983).

Hedge and Walthall (1963) and Allègre (1987) agreed that variations in initial ^{87}Sr/^{86}Sr ratios may have resulted from Rb/Sr fractionation (differentiation), since Rb is an alkali metal and Sr an alkaline-earth metal. Therefore, Zheng (1989) maintained that the three variables ^{87}Rb, ^{87}Sr, and ^{86}Sr are not independent of each other and thus the measured ^{87}Sr/^{86}Sr and ^{87}Rb/^{86}Sr ratios are not necessarily two independent variables on the Rb-Sr isochron diagram. Furthermore, he argued cogently that because geological systems cannot have a homogeneous ^{86}Sr distribution, and because ^{86}Sr is used as a common variable in the conventional isochron equation, the observed isochronous correlations in ^{87}Sr/^{86}Sr vs. ^{87}Rb/^{86}Sr plots are enhanced and induced due to the function of ^{86}Sr as the common denominator. Thus, Rb-Sr dating of both young and ancient volcanic rocks is unreliable.

U-Th-Pb Dating of Volcanic Rocks

Due to the documented problems with the K-Ar, Ar-Ar, and Rb-Sr methods, the U-Pb, Th-Pb, and especially Pb-Pb methods have become the "must use" geochronological tool. However, the same inherent problems with the other age-dating methods have also been documented to plague the U-Th-Pb methods.

Of major concern is open-system behavior as the U-Pb and Th-Pb systems rarely stay closed due to the mobility of Pb, Th, and especially U, under conditions of low-grade metamorphism and superficial weathering (Dicken, 2005). Indeed, U can be lost from samples with no discernible effects of alteration, so it has been suggested that leaching of U from surficial rocks might be a universal phenomenon, and elemental mobility is possible to depths of several hundred meters (Stuckless, 1986), which thus also perturbs the daughter Pb. The identified factors that control U and/or Pb mobility include lattice sites in minerals for U and its daughter products, access of groundwater to those sites, and the volume and chemistry of the circulating groundwater.

In practice, therefore, the mobility of U, Th, and Pb renders their use for U-Pb isochron dates very limited (Dickin, 2005), this open-system behavior largely invalidating U-Pb dating of rocks. This is why the focus has shifted to using the U-Th-Pb dating methods on minerals, such as zircon ($ZrSiO_4$), making that the most widely-regarded benchmark radioisotope-dating methods currently in use, including for age-dating volcanic rocks. In zircon, similar-sized U^{4+} ions substitute in its lattice for Zr^{4+} whereas larger Pb^{2+} ions do not fit into the zircon lattice. So it is claimed that when zircon crystallizes, no Pb is incorporated into its lattice, and thus all the Pb now measured in zircon is due to subsequent in situ radioisotope decay of the U that was incorporated in the zircon lattice when it crystallized.

However, the fundamental problems inherent in the radioisotope dating methods due to the underlying assumptions still apply to the U-Th-Pb methods, even to minerals such as zircon. Snelling (2017a, b, 2018, 2019) reported in detail these problems, documenting them from the conventional literature. These are respectively the inability to precisely determine the ^{238}U and ^{235}U decay rates, the incorporation at crystallization of common Pb that also includes non-decay-derived ^{206}Pb and ^{207}Pb, the mobility of U and Pb, and the mass fractionation of U and Pb isotopes both naturally and during analyses.

Wasserburg (1963) and Wetherill (1963) derived equations to describe steady Pb loss by diffusion resulting from radiation damage to crystal lattices. Goldrich and Mudrey (1972) argued that radiation damage of U-rich mineral lattices as a result of the α-decay of U, Th, and their daughters formed micro-capillary networks which became fluid-filled, the fluids dispersing the non-bound Pb diffusing from those crystal lattices. Meldrum et al. (1998) confirmed that radiation damage drastically increases the rate of Pb diffusion. Furthermore, while the diffusion rate is slow, higher temperatures induce faster diffusion, as dramatically demonstrated by Davis et al. (1968). In the same contact metamorphic zone of Precambrian metamorphic rocks intruded by the Eldora granitic stock in the Colorado Front Range, in which the K-Ar and Rb-Sr isotope systems had been perturbed in several minerals (Figure 1), within 50 feet of the contact the ^{238}U ages of zircon crystals dropped from 1405 Ma to 220 Ma while the ^{207}Pb concentration dropped from 150 ppm to 30 ppm (Figure 3).

Zircon crystals are often zoned, reflecting growth during crystallization, but both zoned and unzoned crystals may be found in the same rock. Pidgeon (1992) demonstrated that unzoned crystals can be the result of recrystallization of zoned crystals accompanied by loss of U, Th, and Pb, and resetting of the U-Pb ages. With the advent of ion microprobes with their very narrow ion beams able to target 2 μm-wide spots, different growth zones within crystals can be dated. Utilizing the SHRIMP (sensitive high-mass resolution ion microprobe), Compston (1997) found that radiogenic Pb varied within most tested zircon grains on a 20 μm spatial scale. Some spots were characterized by huge excesses of ra-

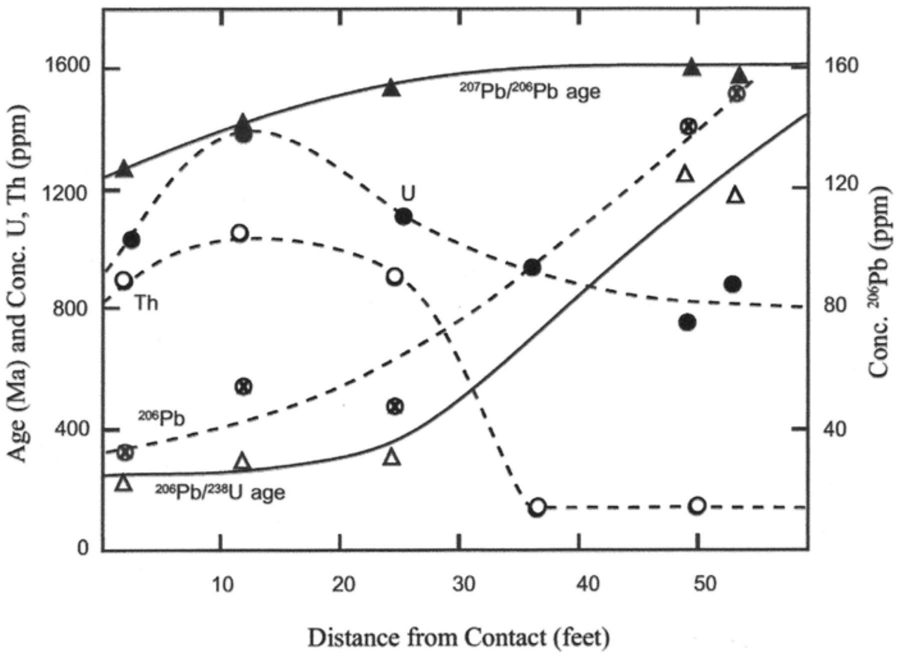

Figure 3. Change in ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ages and in concentrations of U, Th, and ^{206}Pb in zircons in Precambrian metasediments and metavolcanics as a function of distance from the contact with the Tertiary Eldora granite stock, Colorado [after Davis et al., 1968].

diogenic Pb up to 30 times the expected values. Furthermore, Wingate and Compston (2000) demonstrated that there were pronounced reproducible differences in ^{206}Pb/^{238}U ratios and thus ages between four differently-oriented faces of a large baddeleyite (ZrO_2) crystal as well as correlated variation in ^{208}Pb/^{206}Pb with ^{232}Th/^{238}U (Figure 4a, b). And in a second experiment, isotopic ratios were measured on the same crystal faces of 47 baddeleyite crystals but at different orientations with the SHRIMP's beam over a 180° range, the results revealing a striking, approximately sinusoidal, variation in ^{206}Pb/^{238}U ages with orientation (Figure 4c). Also, ^{208}Pb/^{206}Pb and ^{232}Th/^{238}U both varied with orientation in zircon and monazite ([Ce, La, Th] PO_4) crystals.

Another significant problem for zircon U-Pb dating are zircon crystals in some granitic rocks that yield much older ages than the accepted ages of the rocks. These older zircons are usually interpreted as being inherited from the source rocks that melted to produce the magmas (Williams et al., 1983; Chen and Williams, 1990). However, Davis et al. (1968) demonstrated that similar temperatures had a dramatic effect on zircon U-Pb ages (Figure 3). In some published studies, the supposedly inherited zircon grains are 5–10 times older than those matching the accepted ages of the granites—up to 1753 Ma in a 21 Ma, Himalayan granite (Parrish and Tirrul, 1989), up to 3500 Ma in a 426-Ma, south-east Australian granodiorite (Williams, 1992), and up to 1638 Ma in a 370-Ma, New Zealand granite (Muir et al., 1996). Furthermore, a 20-Ma, Himalayan granite contained zircon grains yielding U-Pb ages up to 1483 Ma and monazite grains yielding negative U-Pb ages, such as -97 Ma (Parrish, 1990)!

Deciding on whether anomalous zircon U-Pb ages are due to open-system behavior (such as Pb loss) or whether the zircon grains have been inherited thus depends on the ages expected by the investigators. Indeed, if Pb is lost from some mineral grains, which can be accelerated by heat, water, radiation damage, and even weathering, then it can be inherited by other crystals, such as the Pb presumably lost from the monazite in the 20-Ma, Himalayan granite (above) probably being inherited by its zircon grains. Williams et al. (1984) found unsupported (excess) radiogenic Pb in a zircon crystal in an Antarctic gneiss, which thus produced anomalously high ages. Similar situations also result in ages hundreds of millions of years more than expected and are interpreted as due to excess radiogenic Pb, the origin of which is either explained as mixing from older source materials which melted to form magmas, and/or due to subsequent migration as a result of fluids, temperature, and pressure (Copeland et al., 1988; Zhang and Schärer, 1996). This begs the question—should anomalously old zircons be interpreted as inheritance of the zircon crystals, or of the excess radiogenic Pb in the crystals?

Now Pb is widely distributed throughout the Earth, and thus the isotopic composition of Pb varies within wide limits, from the highly radiogenic Pb in supposedly very old U-bearing minerals to the common Pb in minerals such as galena (PbS) that have low U/Pb and Th/Pb ratios. Lead is also a trace element in most rocks, its isotopic composition being a record of the chemical environments in which the Pb may have resided, including within the Earth's mantle. Thus, the Pb isotopic compositions in rocks display complex patterns of variation that supposedly reflect their particular geologic histories, all of which is relevant to Pb-Pb dating.

The Earth's mantle is increasingly being recognized as the key component of the Earth's make-up, mantle convection not only being the driving force behind plate tectonics but the means by which rocks, minerals, elements, and isotopes are mixed and differentiated into different reservoirs. Isotopic analyses of ocean island basalts were first used to demonstrate mantle heterogeneity. Gast et al. (1964) found significant differences in Pb isotope ratios within suites of volcanic rocks on Gough and Ascencion Islands in the Atlantic Ocean. Subsequently, Tatsumoto (1966) found variations between the Pb isotopic compositions of mid-ocean ridge and ocean island basalts. Many subsequent studies of the Pb isotopic compositions of ocean island basalts found they define a series of linear arrays that are Pb-Pb isochrons corresponding to Pb-Pb ages of between 1 Ga and 1.5 Ga for what are only recently-erupted lava flows (Sun, 1980). The differences in Pb isotopic ratios among volcanic rocks from different islands in the Atlantic and Pacific Oceans indicate the apparent heterogeneity of the upper mantle is a worldwide phenomenon and is not restricted to one or two anomalous islands.

These Pb-Pb isotopic linear arrays or false Pb-Pb isochrons for ocean island basalts can be interpreted as resulting from discrete mantle differentiation events or as the products of two-component mixing processes (Faure, 1986; Dicken, 2005, p.149). Indeed, the presence of Pb with different isotopic compositions in the heterogeneous upper mantle permits mixing to occur during the formation of basalt magmas (Sun and Hansen, 1975). Therefore, the significance of false Pb-Pb isochron data arrays for mid-ocean ridge and ocean island ba-

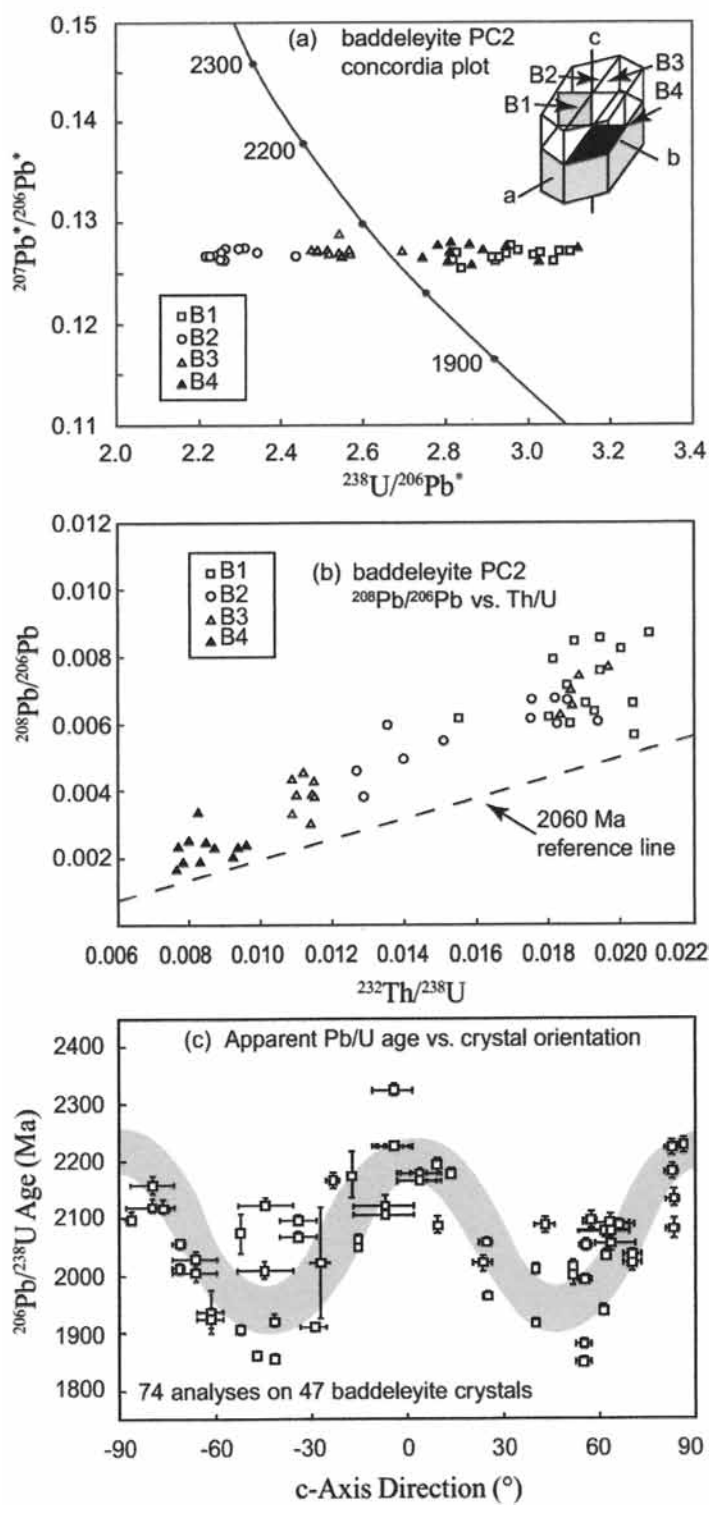

Figure 4. SHRIMP analytical results for baddeleyite, illustrating observed orientation effects [after Wingate and Compston, 2000]. (a) A U-Pb evolution (concordia) diagram showing apparent ages for four differently oriented surfaces (shown in the inset) of a single baddeleyite crystal (PC2 from the Phalaborwa carbonatite, South Africa). (b) Correlated variation in total ^{208}Pb/^{206}Pb with ^{232}Th/^{238}U for the same surfaces measured in (a). (c) Variation of apparent ^{206}Pb/^{238}U age with orientation for (100) surfaces of 47 oriented baddeleyite crystals.

salts remains elusive, because they have more radiogenic Pb in them than they should have if the Earth's age is 4.57 Ga (Dickin, 2005)! This problem has been called the "lead paradox" and still remains unsolved. What is clear is that Pb-Pb dating of these recent basalts produces anomalous old ages that represent the inheritance of the Pb isotopic compositions of the magmas' mantle sources.

The Pb isotopic compositions of volcanic rocks on the continents also form linear arrays that represent false Pb-Pb isochron ages. For example, Moorbath and Welke (1969) found that the wide variety of volcanic and plutonic rocks, both granitic and basaltic, on the Isle of Skye in northwest Scotland lay on a strong linear array on the $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram with a Pb-Pb isochron age of ~3 Ga. They interpreted the linear array as a mixing line between radiogenic mantle-derived Pb and very unradiogenic Archean crustal Pb of the basement Lewisian Complex. By plotting $^{208}P/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ Thompson (1982) identified three Pb isotopic components in the Skye volcanic rocks. Those lavas were therefore interpreted as mantle-derived magmas that had suffered strong contamination in the granulite-facies lower crust during their ascent.

Faure (1986, p. 327) thus offers an important word of caution—"not all linear arrays on the Pb-Pb isochron diagram are isochrons." Linear correlations of Pb isotopic ratios for volcanic rocks can also result from mixing of leads of different isotopic compositions in varying proportions. The pitfalls of distinguishing mixing lines from isochrons affects the interpretation of Pb isotopes in young volcanic rocks. Thus, if young volcanic rocks yield false Pb-Pb isochrons that are mixing lines then Pb-Pb isochrons obtained from older volcanic rocks may likewise be due to mixing. Even if the original colinearity of Pb isotope ratios on mixing lines may be modified by subsequent decay of U and Th, which ultimately scatters the ratios off the line, the original initial colinearity due to mixing remains significant. The present-day U-Th-Pb isotopic ratios therefore do not represent the ages of the volcanic rocks and may result in false Pb-Pb isochrons.

Discussion

From this brief survey of the problems with the four principal radioisotope methods for age-dating of volcanic rocks, namely, K-Ar, Ar-Ar, Rb-Sr, and U-Th-Pb, several observations can be made.

First, many of the conventional sources used here to document the problems with these age-dating methods are several decades old, so why are there not more recent literature sources? The answer is straightforward. Since documentation of the problems with each of these methods early in the history of their use, the scientific community is today more careful in admitting these problems, so there appear to be fewer papers documenting them. Instead they tend to only use those radioisotope dating methods that they remain confident work well. Otherwise, to continue admitting these problems would undermine their narrative that the Earth's 4.57 Ga history has been successfully unraveled from the strata pages of the rock record, each dated as successively millions of years between them. Even geologists generally have not been exposed to these "trade secrets" of geochronology so they, like the general public, believe the millions of years are established fact.

Yet these problems persist, as the more recent textbooks continue to document them. For example, Faure (1986) extensively documented and discussed these problems of inheritance, open-system behavior, contamination, and mixing in the second edition of his textbook. Then Faure and Mensing (2005) simply repeated the same extensive documentation with few new updated examples, except for more documentation of mantle and crustal isotopic domains, inheritance from them, and mixing between them, as reported by Snelling (2005). Similarly, Dickin (2005, pp. 136–173) in the second edition of his textbook also repeats all the same examples documenting these problems as in the first edition, as do Rollinson and Pease (2021, pp. 178–218) in the second edition of Rollinson (1993, pp. 215–265). These textbook examples document that nothing has changed in the decades since these problems were first admitted, and that it is still valid to use the older documentation of examples that adequately, cogently, and comprehensively describe these problems, as done here.

Second, even in the conventional (uniformitarian) literature there is extensive documentation of the multiple problems with these methods. These problems stem from the assumptions on which those methods are based. The initial conditions are unknown and are assumed for ancient volcanic rocks, yet present volcanic rocks frequently record inheritance of their isotopic compositions from their sources, both upper mantle and lower crustal sources. Then contamination frequently occurs due to open-system behavior. During magma ascent, mixing can occur with wall-rocks, and then after extrusion and crystallization, parent and/or daughter isotopes may be lost from volcanic rocks or their constituent mineral crystals via diffusion, leaching by fluids, or even weathering. And finally, constant decay rates are assumed at today's measured rates, but even those are not yet precisely determined. Furthermore, as Snelling (2014, 2016) discovered, the K and Rb decay rates are calibrated against the ^{238}U decay rate, which has been determined, but not precisely (Snelling, 2017a). There is still uncertainty over the ^{235}U decay rate, so that also affects the desired accuracy of Pb-Pb dates.

In any case, none of these assumptions are even provable, because the past is beyond reach of present direct scientific investigation. No geochronologists were present when the volcanic rocks formed to measure their initial isotopic compositions or those of their constituent minerals. And no geochronologists were present in the subsequent years to check for any open-system behavior and to measure the decay rates. Yet if geochronologists were being consistent in applying their uniformitarian reasoning, they would admit that since these radioisotope systems have the well-documented problems of inheritance, open-system behavior, contamination, and mixing in the present, then such behavior must have happened in the past, thus rendering these methods and the ages for volcanic rocks derived by using them as unreliable, at best.

Third, the conventional geology community trumpets the apparent agreement between the ages for many volcanic rock units derived by these radioisotope methods and their presumed ages based on their relative stratigraphic and/or biostratigraphic positions in the rock record as proving these age-dating methods work. And often there is such agreement, especially where zircon U-Pb ages for volcanic units have been used to date bracketed sedimentary strata. Furthermore, the recognized ages for most volcanic units are those that have been deemed acceptable, and yet they usually do correspond to the correct numerical and stratigraphic order.

However, what is not often mentioned is that the ages assigned to many volcanic units have only been determined using one of these four radioisotope dating methods. Rarely has more than one of these methods been used on the same volcanic rock unit. Yet when two methods have been utilized in the conventional literature, there is often disagreement which is never explained because the unacceptable date is merely rejected as being due to open-system behavior or contamination, just as Austin and Snelling (1998) found.

So, what might we expect if samples from rock units were age-dated by multiple radioisotope methods? Vardiman et al. (2005) reported on an extensive research effort in which it was demonstrated that several sampled rock units yielded different ages when the same samples were subjected to three or more of the radioisotope dating methods (Austin, 2005; Snelling, 2005). It was found that there was a systematic pattern in the resultant ages, the K-Ar isochron age always being the youngest, the Rb-Sr isochron being next youngest, and either the Pb-Pb or Sm-Nd isochron ages being the oldest. As there were also other lines of evidence that a lot of radioactive decay must have occurred in a recent short catastrophic event (fission tracks, radiohalos, helium diffusion from zircons, ^{14}C), Vardiman et al. (2005) concluded that radioisotope decay rates must have been accelerated by up to six orders of magnitude compared to today's slow decay rates during the global Genesis Flood cataclysm. They found that the systematic pattern in the ages obtained by the different methods on the same samples could be explained according to the atomic weights of the parent isotopes and the mode of decay. ^{40}K being the lightest atomic weight and a β-decayer, its decay rate was accelerated much less compared to the heavier α-decaying ^{238}U isotope.

Therefore, the apparent agreement between the radioisotope ages of volcanic rocks and their presumed ages based on their relative stratigraphic and/or biostratigraphic positions in the rock record, plus the observation the radioisotope ages of the volcanic rocks usually match their stratigraphic order, can be readily explained. In a volcanic rock erupted in the first month of the year-long Flood cataclysm, for example, after crystallization the parent radioisotopes would have experienced eleven months' worth of accelerated decay. By comparison, in volcanic rock units erupted in the sixth and eleventh months of that cataclysmic event, and thus progressively laid down higher in the stratigraphic record, the parent radioisotopes would only have experienced six months' and one month's worth of accelerated decay respectively. So these three volcanic rock units today would have progressively younger millions-of-years radioisotope ages in the correct sequence from bottom to top of the stratigraphic record. But their true ages would be six orders of magnitude younger!

Thus, the radioisotope contents of volcanic rocks do not provide their absolute ages, because they are obtained by calculations based on unproven assumptions. However, their radioisotope contents can fingerprint the sources of the magmas. And their calculated ages may indicate when the lavas were erupted during the Earth's history relative to the level at which they are found in the rock record, as well as being a chemical property that enables correlation between volcanic rock layers of identical calculated "accelerated decay" ages in different regions or on different continents.

Summary and Conclusions

The K-Ar, Ar-Ar, Rb-Sr, and U-Th-Pb radioisotope methods used by geochronologists to age-date volcanic rocks are fraught with anomalies which are well-documented in the conventional literature. These anomalies are due to the unproven assumptions on which these methods are based that are erroneously regarded as reliable. However, if the present is any guide to the past, then the experimentally-determined inheritance by recently-erupted volcanic rocks of daughter isotopes from their mantle and crustal sources that invalidate their radioisotope ages should also indicate the radioisotope ages obtained on ancient volcanic rocks cannot be trusted either. Similarly, open-system behavior after recently-erupted lavas crystallize, such as excess ^{40}Ar*, or diffusion loss of ^{40}Ar*, diffusion loss of Pb, fluid movements of K, Rb, Sr, U, Th, and Pb, and contamination with and mixing of wall-rock isotopes during magma ascent, should also indicate the radioisotope ages obtained on ancient volcanic rocks cannot be trusted either.

Yet, there is often agreement between the ages of volcanic rock units obtained by these radioisotope methods and their presumed ages based on their relative stratigraphic and/or biostratigraphic positions in the rock record, plus the radioisotope ages of the volcanic rocks usually match their stratigraphic order. However, most volcanic rock units are only age-dated by one radioisotope method and the radioisotope ages obtained may be rejected if they do not match the expected stratigraphic or biostratigraphic ages.

Instead, when volcanic rocks are age-dated by multiple radioisotope methods they often yield wildly different, but systematic, old ages according to the parent radioisotopes. These anomalous ages can be reconciled by postulated accelerated radioisotope decay in a recent catastrophic event, such as the global Genesis Flood cataclysm; the systematic old ages being due to the different atomic weights and modes of decay of the parent radioisotopes. This then explains why the accepted conventional ages match the depositional order in the stratigraphic record.

Taking all these considerations together, the absolute millions-of-years ages for volcanic rocks claimed in the conventional literature using these radioisotope age-dating methods are simply unreliable. However, where there is often agreement between these claimed ages for volcanic rocks and their stratigraphic positions and presumed biostratigraphic ages in the rock record, these highly-inflated radioisotope ages are reconciled by the accelerated decay of the parent radioisotopes during the recent global Genesis Flood cataclysm. Although this working model has some challenges, such as a plausible mechanism, dispersal of heat, and other Earth and space consequences, ongoing research to resolve such challenges continues to validate it as a plausible reconciliation.

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Towards a Rigorous Methodology for Quantifying Truncation of Anticlines: A Case Study at Mount St. Helens

Edward A. Isaacs

Abstract

The regional-scale erosion of hundreds to thousands of meters of stratigraphy remain one of the most pivotal yet debated arguments within Flood Geology. Despite the many previous studies of erosion of anticlines as one illustration of regional-scale erosion, no rigorous mathematical model has been proposed for systematic and repeatable modeling of fold surfaces for erosion estimates in data scarce locations. As such, this study proposes a boundary-value problem approach for modeling symmetric and non-verging fold systems. Applied to folds in the Mount St. Helens region, the model performed well in describing characteristics of the half-wavelength of the fold system. The modeled surface resulted in a calculation of 6.16 km of vertical relief eroded from the current topography, a value that could be increased to 10.1 km when transferring the modeled surface to the outermost observed fold surface. Site-specific geology suggests an additional 1 to 4 km of stratigraphy may have rested atop this modeled surface. This application of boundary-value problems represents a promising technique to systematically reconstruct fold systems for erosion estimates. The approach requires minimal inputs that are easily acquired from geologic maps although this limits its application to approximately symmetric and non-verging fold systems. Even so, this technique represents a first step towards developing an easily deployable yet rigorous approach to model fold systems for repeatable and consistent erosion estimates.

Key Words: Differential Geometry, erosion, fold system reconstruction, Mount St. Helens

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Introduction

Regional-scale erosional patterns remain one of the most central yet debated arguments in Flood Geology. The removal of hundreds to thousands of meters of stratigraphy from the surface of a landscape remains difficult to explain within naturalistic geology and its limited erosional power (e.g., Froede, 2004; Oard, 2008; Matthews and Oard, 2015; Isaacs, 2020). Instead, these authors argue that examples of extreme erosion are evidence of past, high-energy erosion on a regional scale consistent with the scales proposed within a Biblically-founded geologic framework (Reed et al., 1996). Although one of the signature arguments of Flood Geology, how such examples of regional-scale erosion fit into the Biblical timeline remains a topic of debate (e.g., Holt, 1996; Whitmore, 2006; Oard, 2017). Some researchers argue that this erosion is a defining characteristic of recessive processes during the late-stage Genesis Flood (Oard, 2017), while others explain many surficial examples of regional-scale erosion as resulting from post-Flood catastrophism while the world tended towards a state of quasi-equilibrium before the post-Flood Ice Age (Whitmore and Garner, 2009; Whitmore, 2013). Despite this debate being pivotal in the overarching Flood/post-Flood controversy, no work has been done to develop a systematic, mathematically rigorous approach to calculating truncation of anticlines despite their frequent mention in this literature.

The lack of methods for reconstructing anticlines is in part due to the continual challenge that modeling structures pose in industry and academia (Carrera et al., 2009). Traditionally, fold systems are reconstructed using structural contours, which are defined by the intersection of geologic units and topographic contours. However, this can be extremely tedious by hand and requires sufficiently exposed bedrock geology. Alternatively, mathematical models have been developed for interpolating between points where X, Y, and Z values are known. These models generally can only be applied to thoroughly mapped locations with abundant data such as GPS points, cores, and seismic imaging, which are unavailable for many geologic structures (Carrera et al., 2009; Hou et al., 2023; and references therein). In the absence of alternative methods for data scarce structures, Flood geologists have employed various empirical back-of-the-envelope approaches for estimating the scale of erosion (e.g., Oard, 2008; Matthews and Oard, 2015; Isaacs, 2020).

Given the integral nature of this question for other overarching questions in Flood Geology, it is important to develop consistent and mathematically rigorous techniques for estimating regional-scale erosion in data scarce locations. To that end, this paper investigates an application of differential geometry to develop a simplified mathematical model to reconstruct truncated symmetrical anticlines with vertically oriented axial planes (that is, non-verging). This approach is illustrated with a case study in the Mount St. Helens region to estimate the level of vertical erosion (truncation) of the Lakeview Peak Anticline stratigraphy.

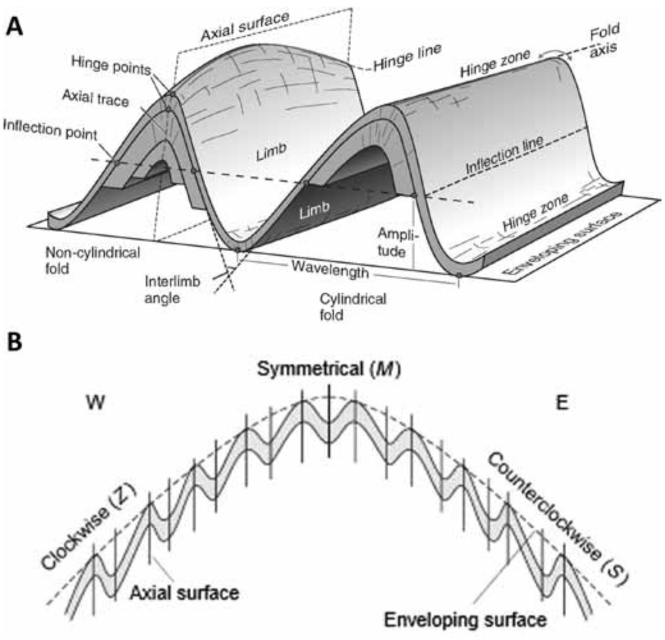

Figure 1. A) Anticline-syncline fold systems are commonly conceptualized as cylindrical curves that are formed from the shortening and compression of what were once planar beds. Note that beds are folded parallel to each other to create a sequence of parallel cylindrical surfaces where a single function could be used to describe the shape of each individual bed. The axial surface is the plane that intersects the hinge points (peak) of each folded bed in an anticline. When a series of parallel axial surfaces are non-vertical (e.g., slanted to the west), it is referred to as vergence (such as "westward verging folds"). Figure after Fossen (2016). B) Folds may also be combined into composite structures like anticlinoria, which are comprised of many smaller parasitic folds along the overarching enveloping surface of the composite structure. Note that axial surfaces are vertical meaning that this fold has no vergence. Figure after van der Pluijm and Marshak (2004).

Geologic Applications for Differential Geometry

As an application of calculus, differential equations are frequently used when describing infinitesimally small

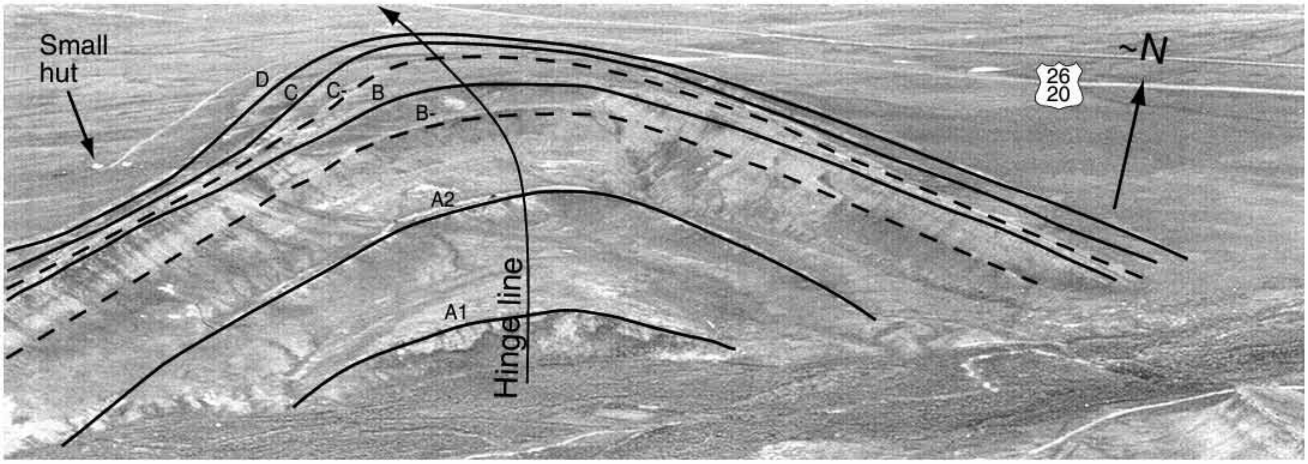

Figure 2. Oblique aerial photograph of the Emigrant Pass anticline in Wyoming. Tracing by Bergbauer and Pollard (2004) used to reconstruct the anticline shape using differential geometry. Figure from Bergbauer and Pollard (2004).

changes in one or more properties necessary to model a natural phenomenon. As such, geomorphology frequently employs differential calculus to derive equations to describe processes such as stream flow and isostasy or to develop landscape evolution models (Pelletier, 2013; Bierman and Montgomery, 2014). Differential equations need not be used only for deriving quantitative relationships between variables but can also be used to describe geometry, such as curvilinear features such as anticline-syncline fold systems. Resulting from the compression of originally planar beds into a curved geometry, fold systems are frequently illustrated as sine-cosine waves and assumed to be cylindrical. As such, Fourier systems, or the sum of an infinite number of sine and cosine functions, is the basis for describing the general shape of fold geometries (Fossen, 2016, p. 258). Hudleston (1973) used a simplified Fourier system to describe fold geometry as approximating the curve:

$$f(x) = b_1 \sin(x) + b_3 \sin(3x) + b_5 \sin(5x) \ldots$$

Where coefficients b_n are unique to the folds being described. Using this Fourier system, folds can be described of a variety of geometries including when their axial plane is nonvertical (that is, verging folds; see Figure 1) though not when they are recumbent. When folds are harmonic, beds are folded parallel to each other so that the function that describes one bed can be applied to all other parallel beds (Fossen, 2016, pp. 258–259). However, folds do not always follow these generalized systems, as has been illustrated at Emigrant Pass in Wyoming (Figure 2) (Bergbauer and Pollard, 2004). Using GPS points to constrain the geometry, Pollard and Fletcher (2005, pp. 116–119) apply best-fit lines through eight cross-sections to illustrate the approximate shape of the fold (as shown in Figure 3). Although asymmetrical, these shapes remain reminiscent of sine-cosine waves that can be modeled by differential geometry.

A Boundary-Value Approach to Modeling Symmetrical, Non-Verging Anticlines

The continual challenge in geomathematical modeling is balancing the precision of the technique and the availability of data. For instance, most geologic mapping projects will not include a series of GPS points for constraining differential geometric models of fold systems. However, regional geologic maps will frequently record several key pieces of information when mapping fold systems:

1. Strike and dip measurements of bedding planes along the fold system.
2. Approximate elevation of strike and dip measurements as shown plotted on a topographic map.
3. The axial trace (that is, the axial plane of the fold intersecting the land surface) calculated through a stereonet analysis of collected strike and dip measurements of folded units.

With this information, the approximate wavelength between interpreted folds can be known as well as the axial plane of wave minima (synclines) or maxima (anticlines)

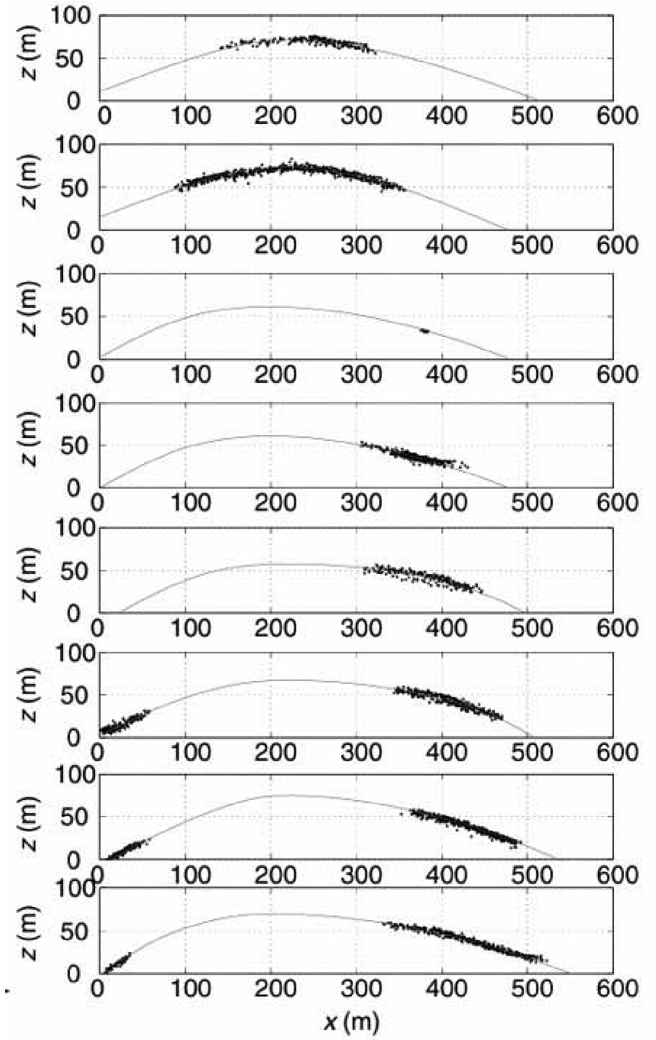

Figure 3. Eight profiles of the Emigrant Pass anticline in Wyoming that show best fit lines through GPS control points to constrain the modeled geometry of the anticline. Note that, although asymmetric, the modeled surfaces are still reminiscent to sine-cosine waves. Figure from Pollard and Fletcher (2005, pp. 116–119).

and a series of points of known location and bedding slope. This provides the constraints for a boundary-value problem, a specific category of ordinary differential equations where a point of known position and slope is needed to reconstruct the curvilinear geometry. We can define one generic boundary-value problem differential equation as:

$$y'' + a^2 y = 0$$

Where a is a coefficient that captures "half wavelength" $\lambda_{1/2}$ or the distance between adjoining maximum (peak or anticline) and minimum (trough or syncline):

$$a = \left(\frac{\pi}{\lambda_{\frac{1}{2}}}\right)$$

In this system, $y(x)$ is the function that describes the fold geometry of interest and where $y(0)$ is the elevation of the strike and dip measurement of interest (that is, the position of a point of known slope). The first differentiation $y'(0)$ is equal to the slope of the strike and dip measurement of interest. With a, $y(0)$, and $y'(0)$ known, this system can be solved by hand or with a variety of online, ordinary differential equations (ODE) calculators. The generic solution is:

$$y = C_1 \cos(ax) + C_2 \sin(ax)$$

Solving for coefficients C_1 and C_2 using the initial conditions $y(0)$ and $y'(0)$ to create a system of equations will yield the function that describes the modeled fold surface. It is important to note the sign convention. Positive $y(0)$ and $y'(0)$ will be for systems where the nearest anticline is to the right and the nearest syncline is to the left. If the reverse is the case, the values of $y(0)$ and $y'(0)$ will be negative.

If the fold is harmonic, beds are parallel so that the function calculated for one bed surface can be moved vertically in space to fit to other beds in the sequence. This is important given that the modeled bed surface may not be the uppermost folded surface in the sequence. On flat terrain, this uppermost surface would be exposed in the center of the syncline in plan view, which may consequently have the least data given its minimal exposure. The model function, however, can be vertically translated in space until the model syncline axis coincides with the mapped syncline axis.

The model will work for the desired fold system assuming that the fold system is non-verging, symmetrical, and cylindrical. For some folds, this will be adequate to approximate the fold surface. The level of truncation (that is, the erosion of the highest original point of the fold to the current land surface) can be calculated as the difference between the elevation of the initial point $y(0)$ and the maximum elevation on the fold.

Case Study at Mount St. Helens

Although known for its 1980 eruption, Mount St. Helens is but the latest example of a long history of volcanism along the Cascadia Magmatic Arc (Cheney, 2014). Volcanic activity dominated the region beginning in the Eocene, result-

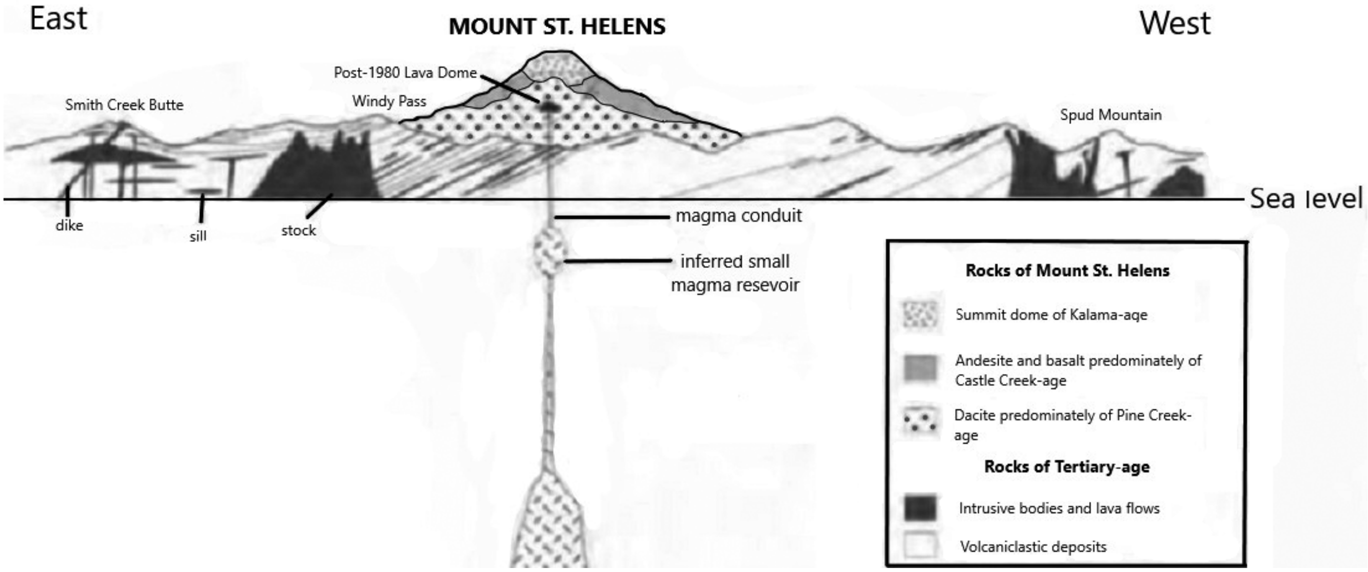

Figure 4. A cross section of Mount St. Helens and the underlying eastward dipping limb of the Lakeview Peak Anticline to the west and adjacent Pole Patch Syncline to the east. Modified from Pringle (2002).

ing in a record of explosive and effusive eruptive products even before the formation of Quaternary stratocones like Mount St. Helens (Evarts et al., 1987). Eocene to Miocene volcaniclastics and lavas are folded in a series of parasitic folds in the Cascade Anticlinorium, an anticlinal composite fold comprised of many smaller, parasitic anticlinal and synclinal folds from southern British Columbia to northern California (Cheney, 2016). Mount St. Helens straddles two of these parasitic folds: the Lakeview Peak Anticline to the west and the Pole Patch Syncline to the east (Figure 4) (Evarts et al., 1993; Evarts, 2001). Consequently, Mount St. Helens volcanic products overlay a series of Oligocene to Miocene volcanics that dip to the east (Figure 5).

Isaacs (2020) attempted to extrapolate the observed anticlinal surface to estimate the vertical relief that has been eroded from the region. By using trigonometry to describe a sine function, Isaacs calculated that the crest of the anticline was at least 7.85 km above the current landscape. However, this approach is a back-of-the-envelope method that assumes that the arbitrarily chosen sine function adequately models the fold system, which may or may not be the case. The previously described ordinary differential equation negates this problem by using specific geometric information to model the original anticlinal surface in a mathematically rigorous and repeatable way.

As shown in Figure 6 (Isaacs, 2020), the distance $\lambda_{1/2}$ between the Pole Patch Syncline and Lakeview Peak Anticline is 44.2 km. Slopes near the Smith Creek Butte, the point of known elevation and slope used in Isaacs (2020), vary between 20° and 25°. For $y'(0)$, we will choose 20° or 0.349 radians (rad) as it will assume a more gentle slope and thereby lower anticline crest elevation to give a minimum level of vertical truncation. As such, we can solve the system:

$$y'' + \left(\frac{\pi}{44200\ \text{m}}\right)^2 y = 0, y(0) = -1130\text{m},$$
$$y'(0) = -0.349$$

Note that we are setting $y(0)$ and $y'(0)$ to negative values because the nearest syncline is to the east and the nearest anticline is to the west when facing north (see earlier description). Our resulting modeled function is:

$$y = -1130\cos\left(\frac{\pi}{44200}x\right) - 5120\sin(\frac{\pi}{44200}x)$$

This function is shown in Figure 7; notable geometric values that come out of this function are noted in Table I. The elevation difference between $y(0)$ and the peak of the modeled anticline is 6.16 km.

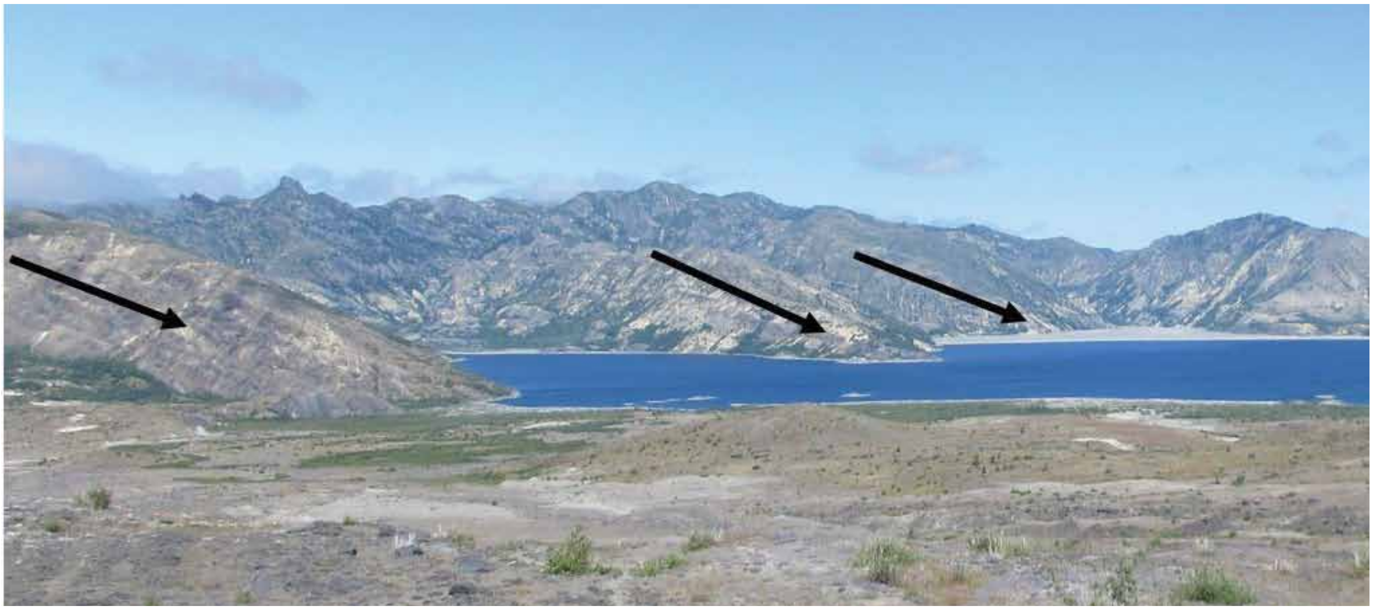

Figure 5. The deforestation along the northern regions of Mount St. Helens during the 18 May 1980 eruption left the eastwardly dipping formations (denoted by arrows) of the west limb of the Pole Patch Syncline strikingly visible around Spirit Lake.

Discussion

From this case study of Mount St. Helens, we can inspect the performance of the proposed differential equation for modeling anticlines and by extension the scale of regional erosion. As noted in Table I, The distance from $y(0)$ to the axis of the modeled syncline and modeled anticline is 14.3% and 10.7% from their mapped counterparts, respectively (when comparing to their measured distances in Figure 6). This illustrates that, despite the fold system not following the assumption of symmetrical and non-verging, the modeled function performs well in describing the constraints concerning the half-wavelength $\lambda_{1/2}$ of the mapped fold system.

The elevation difference between our initial point of interest and the peak of the modeled anticline is 6.16 km, implying that 6.16 km has been eroded from the anticline's crest to the current land surface. However, the point of interest is not on the outermost bed of the fold system. As discussed earlier, in harmonic fold systems the beds will be parallel to each other, allowing the function determined for one bed to be vertically translated to fit to other known beds in the sequence to show the uppermost exposed surface. Assuming an average elevation of 1130 m on the modern terrain, the modeled surface would be translated vertically 3.90 km to match the elevation of the uppermost known folded surface that is exposed in the Pole Patch Syncline (as illustrated in Figure 7). As such, the total estimated eroded relief reaches a value of 10.1 km.

Swanson (1992) noted that even the exposed stratigraphy of the Pole Patch Syncline may not have been the uppermost surface of the fold system. Due to the interpreted thermodynamic requirements of post-folding intrusives in the Pole Patch Syncline, Swanson believed that 1–4 km of stratigraphy had been eroded above what is currently the uppermost exposed fold surface, which would represent an additional 1–4 km of vertical erosion on top of the previously calculated 10.1 km. Greater than the previously published estimate of 7.85 km of vertical erosion (Isaacs, 2020), this value remains one of the highest known published estimates for truncation of anticlines, with earlier studies for the Uinta Anticline in Wyoming calculating up to 5.1 km of vertical erosion (Oard and Klevberg, 2008). It must be remembered, however, that this simplified model is an imperfect representation of the fold surface and is thereby only an estimate, as illustrated by the error associated in modeling the limbs of the fold system summarized in Table I. Even so, this approach offers the potential for a consistent mathematically defined methodology that can be translated to sites across regions and compared with similar margins of error and implicit assumptions.

Conclusions

The regional-scale erosion of hundreds to thousands of meters of stratigraphy remain one of the most pivotal yet debated arguments within Flood Geology. Despite the many

Figure 6 *(left)*. A simplified diagram depicting Mount St. Helens and underlying fold system of the Lakeview Peak Anticline and Pole Patch Syncline; arrows denote direction of plunge. The line connecting both Lakeview Peak Anticline and Pole Patch Syncline is a 44.2 km transect representing the distance between axes. The star denotes reference point west of Smith Creek Butte used in Isaacs (2020), while distances between that point and the axes are also shown.

Figure 7 *(below)*. Modeled fold geometry (lower curve) resulting from the boundary-value problem and its vertical translation to the uppermost observed fold surface in the Pole Patch Syncline (upper surface). Vertical line represents average elevation in this area and elevation of $y(0)$. Due to sign convention, $y(0)$ is negative (y-value shown by horizontal line) so that nearest anticline appears to the west (negative x-direction) when facing north.

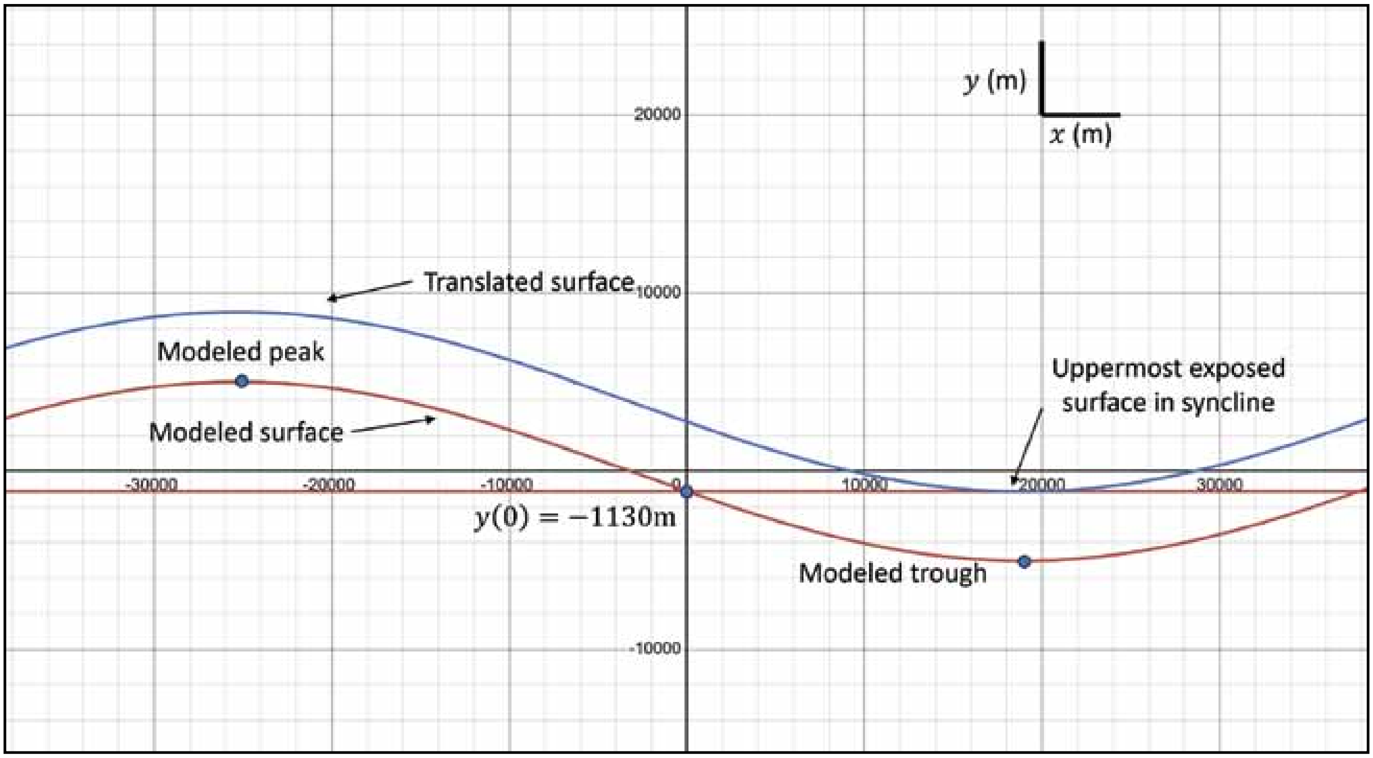

Table I. Comparison of modeled anticline geometry and mapped geometry. Note the percentage error between the model and mapped characteristics of the half-wavelength $\lambda_{1/2}$.

	Mapped	Modeled	Percentage Error
Distance to Anticline	28.0 km	25.2 km	+10.7%
Distance to Syncline	16.2 km	19.0 km	+14.3%
Elevation Difference	NA	6.16 km	NA

previous studies of erosion of anticlines as one illustration of regional-scale erosion, no rigorous mathematical model has been proposed for systematic and repeatable modeling of fold surfaces for erosion estimates. As such, this study investigated differential geometry approaches to reconstruct fold systems.

Using a case study of the Mount St. Helens region, a boundary-value problem was applied to model a symmetric and non-verging fold system. The model performed moderately well (within 15%) in describing characteristics of the half-wavelength of the fold system, giving some level of confidence in the application of this simplified model to this fold system. The modeled surface resulted in a calculation of 6.16 km of vertical relief eroded from the current topography, a value that could be increased to 10.1 km when transferring the modeled surface to the uppermost observed fold surface. Site-specific geology suggests an additional 1 to 4 km of stratigraphy may have rested atop this modeled surface but remains beyond the purview of the mathematical technique.

This application of boundary value problems represents a promising technique to systematically reconstruct fold systems for erosion estimates. The approach requires minimal inputs that are easily acquired from geologic maps (initial elevation and slope, and distance between fold maxima and minima). However, due to the minimal data required to constrain the model, researchers must be aware of the assumptions implicit in the model (e.g., fold system is not strongly verging). Future research may develop alternative approaches using differential geometry that better reflect local site conditions. Even so, this technique represents a first step towards developing an easily deployable yet rigorous approach to create repeatable and consistent erosion estimates.

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The Climate and Environment of the Exodus: Clues from the Birds of Leviticus 11:13–19

Martin Johnson

Abstract

Problems concerning the need for food and water by the flocks and herd of the Israelites are discussed, and also the need for fuel for cooking. This paper argues that the identification of the "banned birds" of Leviticus 11:13–19 points to a very different climate and environment than has been the case for the past three millennia in the territory of the "wanderings of the Israelites." This paper builds on research using onomatopoeic (OP) correlations by Johnson and Jenson (2023) which resulted in the species-level identification of seventeen of the "banned birds."

Ornithology, archaeology, and paleoclimatology all point to the Sinai Peninsula and neighbouring regions having a much higher rainfall, which would have created the conditions where grazing and water for livestock would be available, as well as firewood. The range of habitats then available provides a precise match for the requirements of that group of birds.

This has a bearing on the possible routes for the "Red Sea" crossing, as well as the date of writing Leviticus and the other Torah passages dealing with the "wanderings."

The conclusion is drawn that this specific list of birds points to the "wilderness tradition" of the Israelites being set in a landscape that would have been found in the Sinai region prior to a time around 1250 BC. Finally, consideration is given to the *"-min"* attributions found in the "banned birds" list, with its implications for Hebrew bird taxonomy.

Key Words: desertification, Leviticus authorship, Onomatopoeia, Paleoclimates, Sinai

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Introduction

Many popular films and representations of the journey of the Israelites after the Exodus from Egypt use illustrations of people traveling through stony and sandy deserts, typical of the region to the east of Egypt in the present times. Yet Exodus 12:28 says: "A mixed multitude went up with them also, and flocks and herds—a great deal of livestock." Weeks later they were told to keep them away from the mountain (Exodus 34:3). This raises the question of what the flocks and herds fed on, as transporting large quantities of animal feed is not mentioned. Then there is the issue of water. Only three times in the whole narrative is it stated that they were short of water—three days in the Wilderness of Shur, at Marah (Exodus 15:22–25) again at Meribah (Exodus 17:1–7), and finally, at Kadesh in the desert of Zin, some 40 years later (Numbers 20:1–11).

It is clear that the Israelites kept their flocks and herds throughout this period, and were one of several groups in the region that may be described as "Bronze Age Pastoralists." The only references to food shortages are for the people, remedied with quails and manna (Exodus 16:13, 15, et seq.), leaving open the question of where the food and water for all those flocks and herds could have come from. Then, Exodus 16:23 says "…So bake what you want to bake and boil what you want to boil…" implying the use of cooking fires, which need fuel. It is hoped the research reported here will help to answer these questions.

It will potentially shed some light on the question of the route of the Exodus and wanderings, as well as helping to fix the date of writing Leviticus to near the middle of the 2nd millennium BC.

A further issue covered is the possible taxonomic implications of the "*-min*" attributions as in "according to their kind" found in Leviticus 11 and Deuteronomy 14.

Leviticus 11:13–19 contains a list of "banned birds" and research into the identification of those birds using onomatopoeic (OP) correlations identified seventeen at species level and one more at family level (Johnson and Jenson, 2023). This paper reports research into their habitats, the geographical and environmental conditions where they might be found. These habitats range from wetlands to deserts and mountains, which indicates different environmental conditions than have prevailed in most of the southern Levant (the region to the south of present-day Israel and Jordan) for the past three millennia.

A review of paleoclimates reveals the climate changing from humid to arid in the southern Levant around 1,250 BC.

Eilat at the head of the Gulf of Aqaba is considered as a microcosm of a warm environment with wetlands containing several of the "banned birds" habitats and where the majority of them have been reported recently.

The changing climate becomes more significant when considering the territory of the wanderings of the Israelites in the post-Exodus narrative, which may include the Sinai and Negev deserts and southern Jordan, nowadays a region of arid deserts fringed with mountains. The "wilderness tradition" comprises approximately two thirds of the Torah, and has been a contentious topic in critical scholarship (Hoffmeier, 2005, pp. 3–22). Recently published opinions include that the "wilderness tradition" is a product of the 7th century BC, based on creative imagination rather than historical memories (Finkelstein and Silberman, 2002), or reflects ancient sources preserved in later writings (Soggin, 1984, pp. 19–20), and the view that the writings are a contemporary product of the 15th century BC (e.g., Petrovich, 2016, pp.186–200).

This research supports the thesis of Soggin (1984, pp. 19–20) to a limited extent. It more fully supports that of Petrovich (2016, pp. 15–35, 65–74) where he argues that texts found in the Sinai (and dating from a pre-Exodus period) evidence Hebrew script, in that the list of "banned birds" evidences conditions of the mid-2nd millennium BC in Sinai and its neighbouring territories, although the climate factors indicated by the birds means this applies to most of the Torah as noted above, rather than small segments. It also supports Hoffmeier (2005, pp. 167, 209) when he argues that references to turquoise and Acacia wood help to locate the narrative in Sinai, as it will be shown that the habitats available in the Sinai during the middle of the 2nd millennium BC similarly represent a precise match for the habitats required by the "banned birds" of Leviticus 11:13–19.

This paper presents the habitats, and diets of those birds, which are then considered against known historic distributions of these birds from the central Sahara during its last major humid period and Ancient Egypt, as well as 21st century Eilat. The conclusion is drawn that this list of "banned birds" points to the "wilderness tradition" of the Israelites being set in a landscape that would have been found in the Sinai region prior to a time around 1,250 BC and before the subsequent desertification of this region.

The 19 Birds Identified

The identifications in Johnson and Jenson (2023) were made after reviewing the translations found in the Septuagint (LXX) of the 3rd century BC and the Vulgate Bible of the late 4th century AD, together with ornithology and archaeology, including the availability of those birds in Ancient Egypt. Possible onomatopoeic (OP) correlations were tested, and good-to-strong OP correlations were found for 17 of the 19 birds in Leviticus 11:13–19. The other two were bird 1, *nesher*, where two different eagles gave similar weak positive OP correlations, and bird 8, *tachmas*, where no positive OP correlations were obtained at all, despite several attempts.

The majority of these results support the most ancient translations (N.B. These include the flamingo and ibis!). On the basis of availability in the region throughout recorded history, and prominence within the respective genera these identifications are considered plausible. Table I summarizes those findings in generalized terms, and offers suggested translations accordingly.

The Habitats and Diets of the 19 Birds

Species-level identifications of the 19 birds are supplied below, with habitats and diets. Ornithological data is sourced from Porter and Aspinall (2010) and https://animalia.bio/.

Bird 1—*nesher*: Large brown eagles

This identification was based on weak positive OP responses against the golden eagle *Aquila aetos* (64.3%) and the tawny eagle *Aquila rapax* (68.2%). Given the similarity of eagle calls, it is likely that other large brown eagles of the family *Aquila* known in the region may produce stronger correlations. These are the greater spotted eagle *Aquila clanga*, the steppe eagle *Aquila nipalensis* and the eastern imperial eagle *Aquila heliaca,* which is currently the most numerous of these species in the region.

- **Habitats:**
    - Golden and Tawny Eagles—mountains and plains, including arid semi-desert, and wooded terrain. They may nest in trees (also rocky ledges for the golden eagle).
    - Steppe and Eastern Imperial Eagles—similar terrain, though hill country rather than mountains, and also marshes.
    - Greater Spotted Eagle—wetlands.
- **Diets:** mammals, birds, reptiles, insects, and carrion.

Table I. Proposed English translations of the 19 birds in Leviticus 11:13–19.

	Hebrew		Suggested Translation	Correlations
1	נֶשֶׁר	*nesher*	Eagle	Weak OP, LXX, Vulgate
2	פֶּרֶס	*peres*	Vulture	Strong OP, LXX, Vulgate
3	עָזְנִיָּה	*‘ozniyah*	Short-toed Snake Eagle	Good OP, If Pliny’s *haliaietos*, then LXX, Vulgate
4	דָּאָה	*da’ah*	Kite	Good OP, LXX, Vulgate
5	אַיָּה	*’ayah*	Falcon	Strong OP
6	עֹרֵב	*‘orev*	Raven	Strong OP, LXX, Vulgate
7	בַּת יַעֲנָה	*bath ya‘anah*	Desert Owl	Strong OP
8	תַּחְמָס	*tachmas*	Little Owl	*Not* OP, LXX, Vulgate
9	שַׁחַף	*shachaph*	Seagull	Strong OP, LXX, Vulgate
10	נֵץ	*nets*	Hawk	Strong OP, LXX, Vulgate
11	כּוֹס	*kos*	Long-eared Owl	Good OP, LXX
12	שָׁלָךְ	*shalak*	Cormorant	Strong OP, LXX, Vulgate
13	יַנְשׁוּף	*yanshuph*	Eagle Owl	Strong OP (LXX, Vulgate, implied from *charadrios*)
14	תִּנְשֶׁמֶת	*tinshemet*	Flamingo	Good OP, LXX, Vulgate
15	קָאַת	*qa’ath*	Pelican	Strong OP, LXX, Vulgate
16	רָחָם	*racham*	Crane	Strong OP
17	חֲסִידָה	*chasidah*	Ibis	Strong OP, LXX, Vulgate
18	אֲנָפָה	*’anaphah*	Heron	Good OP, LXX, Vulgate
19	דּוּכִיפַת	*dukiphath*	Hoopoe	Strong OP, LXX, Vulgate

Bird 2—*peres*: Griffon Vulture

The griffon vulture *Gyps fulvus* gave a strong OP correlation (77.3%). It is currently the most numerous type of vulture in the region.

- **Habitat:** all types of countryside including mountains, it nests in caves and cliff ledges.
- **Diet:** carrion.

Bird 3—*'ozniyah*: Short-Toed Snake Eagle

The short-toed snake eagle *Circaetus gallicus* gave a good OP correlation (72.7%).

- **Habitat:** open wooded plains, but also stony foothills and semi-deserts. It nests in trees or cliffs.
- **Diet:** mainly non-venomous snakes, also other reptiles and amphibians.

Bird 4—*da'ah*: Black Kite

The black kite *Milvus migrans* gave a good OP correlation (71.4%).

- **Habitat:** woodland, often near water. It nests on tree branches, cliff ledges, or buildings.
- **Diet:** fish, small mammals, birds, bats, rodents and carrion.

Bird 5—*'ayah*: Peregrine Falcon

The peregrine falcon *Falco peregrinus* gave a very strong OP correlation (89.3%).

- **Habitat**: includes mountains and forests and also marshes and wasteland.
- **Diet:** medium-sized birds, bats, small mammals, insects, and reptiles.

Bird 6—*'orev*: Fan-Tailed Raven

The fan-tailed raven *Corvus rhipidurus* gave a very strong OP correlation (84%).

- **Habitat:** a wide variety of territory between sea level and 3,000 meters, often close to human habitation. It nests on ledges or holes in rock faces.
- **Diet:** insects and other invertebrates, grain taken from animal dung, carrion, and scraps of human food. It also takes skin parasites from camels.

Bird 7—*bath ya 'anah*: Desert Owl

The desert (tawny) owl *Strix hadorami* gave a very strong OP correlation (81.5%).

- **Habitat:** rocky gorges, desert earth banks, often near palm groves, acacias, sometimes near springs and settlements. It nests in holes in rocks or cliff faces.
- **Diet:** voles, mice, and large insects.

Bird 8—*tachmas*: probably Little Owl

No OP correlation was achieved with *tachmas*, but after harmonising the LXX and Vulgate translations, the little owl *Athene noctua* was considered the most likely candidate.

- **Habitat:** open country with trees, semi-deserts, cultivated areas, often near human habitation. They both nest in holes in trees, rocks, and buildings.
- **Diet:** insects and earthworms, small amphibians, reptiles, birds, and mammals.

Bird 9—*shachaph*: Black-Headed Gull

The black-headed gull *Chroicocephalus ridibundus* gave a strong OP correlation (76%).

- **Habitat:** coastal and inland waters, farmland, and wetlands. It nests on open ground and in low trees and bushes.
- **Diet:** insects, fish, seeds, worms, carrion, and invertebrates.

Bird 10—*nets*: Hobby

The hobby *Falco subbuteo* gave a strong OP correlation (76%).

- **Habitat:** (same for all raptors of this size) scattered woodland, and cultivated areas with trees. They nest in old nests (often those of crows).
- **Diet:** large insects, such as dragonflies, also bats and small birds.

Bird 11—*kos*: Long-Eared Owl

The long-eared owl *Asio otus* gave a good OP correlation (70.4%).

- **Habitat:** deciduous woods and copses, also stands of conifers. It usually nests in trees, often in the old nest of another raptor or a crow.
- **Diet:** Its diet is mainly small rodents, especially voles, but also other small mammals, small birds, small reptiles, and insects.

Bird 12—*shalak*: Great Cormorant

The great cormorant *Phalacrocorax carbo* gave a very strong OP correlation (100%).

- **Habitat:** coastal waters and inland lakes. It nests in colonies in trees.
- **Diet:** mainly fish, but it will also eat crustaceans, amphibians, and insects.

Bird 13—*yanshuph*: Spotted Eagle Owl

The spotted eagle owl *Bubo africanus* gave a very strong OP correlation (88.9%).

- **Habitat:** open woodlands, rocky hills, ravines, sometimes near human habitation.
- **Diet:** small mammals, birds, insects, frogs, and reptiles.

Bird 14—*tinshemet*: Greater Flamingo

The greater flamingo *Phoenicopterus roseus* gave a good OP correlation (70.8%).

- **Habitat:** coastal regions, salt lakes, and mudflats. It breeds colonially on mud banks or shallow water lakes where it builds mud heap nests.
- **Diet:** crustaceans, molluscs, worms, crabs, insects, and sometimes small fish.

Bird 15—*qa'ath*: Great White Pelican

The great white pelican *Pelecanus onocrotalus* gave a very strong OP correlation (87.5%).

- **Habitat:** large inland wetlands and shallow water coastal lagoons. It nests colonially in reeds.
- **Diet:** fish, small invertebrates, also small birds, small reptiles, amphibians, and crustaceans.

Bird 16—*racham*: Common Crane

The common crane *Grus grus* gave a very strong OP correlation (90.9%).

- **Habitat:** wetlands, fields, and steppe.
- **Diet:** mainly plant matter, but also insects, snails, earthworms, crabs, spiders, millipedes, woodlice, amphibians, rodents, and small birds.

Bird 17—*chasidah*: African Sacred Ibis

The African sacred ibis *Threskiornis aethiopicus* gave a strong OP correlation (75%).

- **Habitat:** wetlands, cultivated areas, coastal marshes, parks, and large gardens. It nests colonially in trees.
- **Diet:** mainly insects, worms, crustaceans, molluscs, and other invertebrates, also fish, frogs, reptiles, small mammals, and carrion

Bird 18—*anaphah*: Grey Heron

The grey heron *Ardea cinerea* gave a good OP correlation (70.8%).

- **Habitat:** wetlands, including coastal regions. It nests colonially in trees.
- **Diet:** fish, amphibians, crustaceans, aquatic invertebrates, molluscs, snakes, small birds, and rodents.

Bird 19—*dukiphath*: Eurasian Hoopoe

The Eurasian hoopoe *Upupa epops* gave a very strong OP correlation (83.3%).

- **Habitat:** woodland, olive and palm groves, parks, gardens, oases, open and wooded areas. It nests in holes in trees or ruins.

Table II. Summary of "banned birds" habitats.

Hebrew	Proposed Identification	Mountains	Desert	Wooded Plain	Grassland Cultivated Land	Woodland	Inland Wetland	Coastal Lagoons & Marshes
nesher	Eagle (large)	√	√	√	√	√	√	
peres	Griffon Vulture	√	√	√	√			
'ozniyah	Short-toed Eagle		√	√				
da'ah	Black Kite					√	√	
'ayah	Peregrine Falcon	√		√		√	√	
'orev	Fan-tailed Raven	√	√	√	√	√	√	
bath ya'anah	Desert Owl	√	√					
tachmas	Little Owl		√	√	√			
shachaph	Black-headed Gull						√	√
nets	Eurasian Hobby			√	√			
kos	Long-eared Owl			√	√	√		
shalak	Great Cormorant						√	√
yanshuph	Spotted Eagle Owl	√		√				
tinshemet	Greater Flamingo						√	√
qa'ath	Great White Pelican						√	√
racham	Common Crane				√		√	√
chasidah	African Sacred Ibis				√		√	√
'anaphah	Grey Heron						√	√
dukiphath	Eurasian Hoopoe			√	√	√		

- **Diet:** mainly insects, but also small reptiles and frogs.

Anomalies

Two of these birds (*yanshuph* = spotted eagle owl and *chasidah* = African sacred ibis) are not now found north of the Sahara Desert. The African sacred ibis used to be a very common bird in Egypt, as evidenced by the huge number of mummified examples, including 1.75 million at Saqqara and 4 million at Tuna El-Gebel from the period around 450–250 BC (Montgomerie, 2018). The spotted eagle owl, while not recorded in Ancient Egypt, has been reported in some locations on the Arabian Peninsula.

Summary of Habitats

This list of birds covers a very wide range of habitats, mountains, desert, plains, grasslands, woodlands, and inland and coastal wetlands. Only six of the birds are likely to be found in desert areas, and all but the desert owl will also be found in other habitats. Seven of the birds are normally found only in wetland habitats, while a further four are also often found in inland wetlands (Table II). The requirement therefore is to identify territory where this specific combination of habitats can be found within a travelling distance appropriate for Bronze Age pastoralists, as described in the 'wilderness tradition.'

Territory

Figure 1. Satellite image showing the general territory of the wanderings of the Israelites described in Exodus and Numbers (courtesy Google Maps).

This list of birds (and the parallel one in Deuteronomy 14:12–18) is set in the context of the time the Israelites were reported to be wandering following the Exodus. There are four specific references to the Wilderness of Sin (Exodus 16:1, 17:1; Numbers 33:11–12) as a location. This may or may not be the same place as the desert or wilderness of Sinai (a further 13 references in Exodus, Leviticus, and Numbers) which is related to Mount Sinai (17 references in the Torah). While there continues to be debate about the location of the Wilderness of Sin, the route of travel, and the identity of most of the other locations listed in Numbers 33, (Hoffmeier, 2005, pp. 47–73) the general area is contained within the territory shown in Figure 1, which includes the Sinai and Negev deserts, southern Jordan, and northwest Saudi Arabia.

This area today is mostly arid desert. According to Numbers 33:35–36 the Israelites only reached Ezion Geber (at the head of the Gulf of Aqaba) towards the very end of the 40 years of wanderings, which if accepted at face value suggests that the main area covered before then would be in the Sinai and possibly the Negev deserts. These deserts are an eastward extension of the Sahara, and are presently considered "most extreme deserts" (Nicholson, 2011, p. 332). Rainfall varies from around 200mm per year average in the north coastal area to 3mm or less in the south (Elmenoufy et al., 2017). The majority of these birds (13 of 19) would not be found in arid desert.

However, during the second millennium BC, there was extensive grazing land in the Negev, and oaks and olives grew in the Sinai (Neev and Emery, 1995, p. 64). This correlates with a major humid period in the Sahara, which changed from savannah to arid desert around 3,000–4,000 years ago (Nicholson, 2011, p. 432). In Genesis 13:1 it says: "So Abram went up from Egypt to the Negev, with his wife and everything he had, and Lot went with him to the Negev." This implies there was grazing available in the Negev at that time. Recent research around Al-Ula in NW Saudi Arabia has also shown that it was a greener land before 1200 BC with abundant evidence of cattle grazing and also monumental building implying a sizeable population (Royal Commission for al-Ula, 2022).

Various types of proxy records have been utilized to attempt reconstructions of paleoclimates, and for those times before written records are available, these include ocean sediment cores, pollen records, lake sediments, beach ridges, sand dunes, and evaporite deposits. The problem is, "the further back in time, the more imprecise the proxies" (Nicholson, 2011, pp. 485–486).

One paleoclimate study for Egypt suggests that, in the south, rainfall in the distant past could have been above 500mm/year, declining to around 200mm/year in the north, and that higher precipitation existed in the Red Sea mountains. The latter would have been due to orographic rainfall and the influence of Red Sea Troughs in addition to monsoonal and Mediterranean rainfall (Henselowsky et al., 2022). This study is focused on the Last Interglacial Period tentatively dated around 100,000 years ago, but reflecting rainfall and climate patterns proposed for the time period 1,000–10,000 years ago (Nicholson, 2011, p. 492). This is further supported by studies of coral reefs, pollen, land snails, and marine deposits (Klein et al., 1990). Even rainfall of 500mm/year is only enough to sustain grassland with a few trees, so the higher rainfall in the mountains becomes very important for creating the variety of habitats then possible, depending on how that rainwater is channelled.

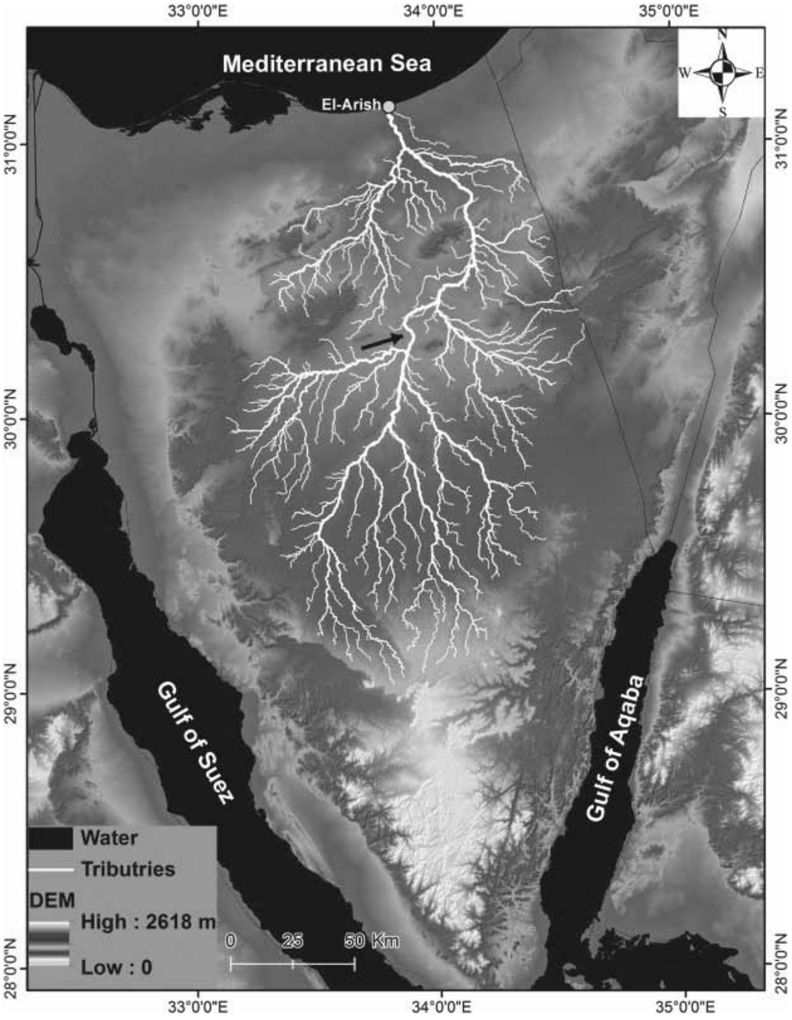

Figure 2. Topography of the Sinai Peninsula overlain with the extracted drainage network of Wadi El-Arish (channel lines within the watershed are shown in white). Credit: Radarsat-1/Shuttle Radar Topography Mission (AbuBakr, et al., 2013).

The existence of ancient watercourses has been observed running across the Sinai Peninsula. AbuBakr et al (2013) analysed radar topography to reveal the extent of the waterway system known as Wadi El-Arish which is just visible in Figure1 but was once much more extensive and channelled water from practically all of the central area of Sinai (Figure 2) and originating in the surrounding 'Red Sea' mountains at the southern end of the peninsula. The Wadi El-Arish drainage area in particular would have been capable of supporting extensive wetlands in many places during those times of higher rainfall, surrounded by savannah desert and mountains. Similar drainage systems have been identified in NW Saudi Arabia, in Al Jow province, some 300 to 600 km east of Aqaba which could possibly have provided similar habitats to Sinai, albeit on a smaller scale, though traveling there would have involved crossing a mountainous region (Abdelkareem et al., 2020).

Desert Kites

In the Negev highlands and northeast Sinai, evidence of human activity in ancient times includes the presence of

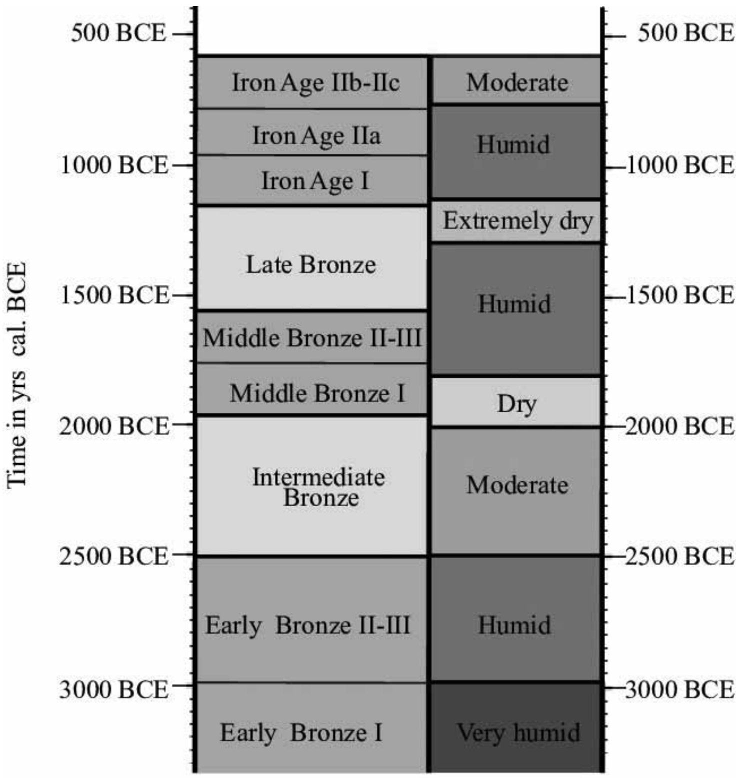

Figure 3. Summary of the climate history of the southern Levant during the Bronze and Iron Ages based on the palynological evidence (Langgut et al., 2015).

“Desert Kites,” funnel-shaped installations comprising long, low walls of local field stones with two long sides converging on a stone-walled enclosure or pit at the apex. These cover an average area of one hectare (i.e., nearly 2.5 acres). Sixteen of these have been identified in the Negev to date, while hundreds more are known in eastern Jordan. These have been explained alternatively as aids to hunting, or as devices to corral and protect domestic herds. They have been found in northwest Saudi Arabia, where they are named mustatils. The use for hunting has been described with similar structures elsewhere, but the re-use of an ancient structure in such a way does not preclude other uses at earlier times, while there is ample evidence of cattle and goat remains in the Saudi Mustatils (Holzer et al., 2010; Kennedy et al., 2023). Svizzero and Tisdell (2018) have reviewed reports on over 5,000 of these structures, and conclude that although some may have been used for hunting, their main use was for mustering cattle, with a possible third function being the capture of animals such as wild goats.

Dating of these structures is tentative, and largely based on charcoal, burnt bone, or sediment which may or may not actually be associated with the original construction, and which has then been subjected to radiocarbon dating. Several of the dates of the Negev structures so derived point to the second millennium BC, around the time of the major humid period in the Sahara mentioned above. At this time, much of the central area of Sinai and the Negev highlands which are mid- and high-altitude plains was savannah and therefore well-suited to grazing by livestock. The desert kites provide corroboration of a population with livestock, though it is not currently possible to determine who those people might have been.

Palynology

Langgut et al. (2015) have attempted a paleoclimate synthesis using pollen records, covering the period from the Early Bronze Age through to the late Iron Age (Figure 3) which shows a major humid period for the southern Levant lasting 500 years across the mid-2nd millennium BC.

The “extremely dry” period beginning around 1250 BC marks the time when the Sinai, the southern Negev, southern Jordan, and northwest Saudi Arabia became arid desert. Although elsewhere in the southern Levant did experience later humid periods, these areas did not. This is because the Mediterranean climate experienced by Israel produces rainfall associated with Mediterranean depressions or cyclones, but this mostly falls to the west of the country (Nicholson, 2011, p. 333).

The Sinai region, on the other hand, is under the control of the Indian and African monsoon systems, and the special factors which drove monsoons further north up the Red Sea providing much higher rainfall during the Early and Middle Bronze Ages do not seem to have recurred since (Finkelstein and Langgut, 2014). This “extremely dry” period marks the driest conditions in the entire Bronze and Iron Age timespan, and “possibly contributed to the Late Bronze Age Collapse” (Langgut and Finkelstein, 2023).

Radiocarbon dating by itself (uncorroborated by other dateable material) is better at providing a general time frame rather than the apparent precision given in Figure 3. Keenan

(2002) lists six different Ancient Near East reports between 1991 and 2001 making this very point, that radiocarbon dating shows large disparities with archaeological dating, making them much older (in the opinion of those archaeologists) than they should be. This is mentioned just to emphasize that when considering times of climate change, we can only say that the change from humid to arid could have taken place somewhere around 1250 BC, but not with the precision that Figure 3 seems to offer.

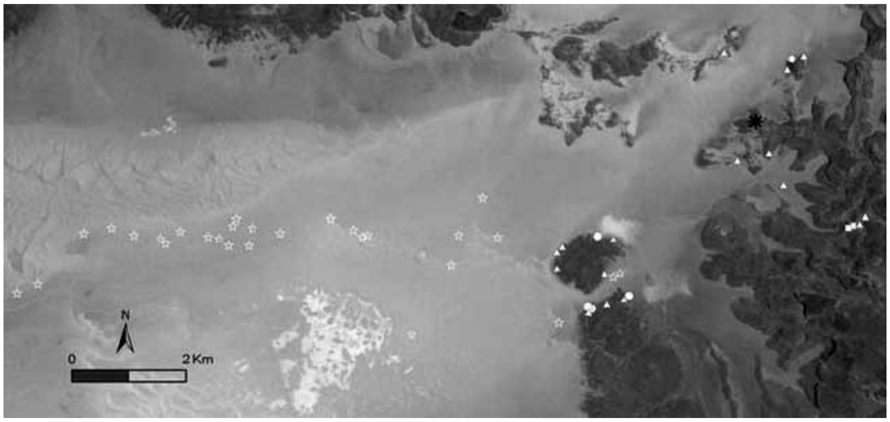

Figure 4. The Wadi Takarkori Project area. Key: asterisk Takarkori rock shelter, star Holocene open-air site, square corbeille (circular stone cairn with standing slabs), circle stone platform, triangle tumulus (adapted from Biagetti and Lernia, 2013; di Lernia and Tafuri, 2013).

Desertification

Desertification is not simply a feature of changing rainfall patterns, as it can be impacted by many factors—including changes in surface vegetation, maximum and minimum temperatures, and wind, as well as human activity including deforestation and overgrazing (Nicholson, 2011, pp. 442–443). This means that a paleoclimate date estimate based on rainfall proxy measures and pollen samples might be different to the date of full desertification. We can say with confidence that the "extreme desert" of the Sinai and Negev was once much wetter, and that during much of the second millennium BC there would have been good grazing for animals and trees for firewood. It also means that there was no need for the Israelites to travel any further afield than the Sinai and Negev areas, though they would need to keep moving on because of probable over-grazing. This suggests one of the possible westerly "Red Sea" crossing routes rather than those to the east of Sinai (see Carter, 2021, for a concise summary of current theories for "Red Sea" crossings). However, such a group—even at the smaller numbers advocated by Hoffmeier (2005, pp.153–159) would undoubtedly have accelerated desertification of the area they were passing through, in a way similar to the 1930s "Dust Bowl" in the USA.

Eilat as a Proxy Location for Bronze Age Humid Period Bird Life

At the head of the Gulf of Aqaba is the modern city of Eilat, close to the location of the ancient city of Ezion-Geber. The climate there is hot and dry, and there used to be some 12 square kilometers of saltmarsh before modern development began in the 1950s, which resulted in a lot of the saltmarshes being drained. The saltmarshes had always been used by migratory birds in the spring, but since the early 1990s, both freshwater ponds and saltwater lagoons have been constructed, which together with the small area of remaining saltmarshes provide an attractive environment for many birds all the year round (Skolnik, 2018).

Most of the birds in the Leviticus 11:13–19 list have been reported there in recent years. These include the the golden eagle, great spotted eagle, steppe eagle and eastern imperial eagle, the griffon vulture, the short-toed snake eagle, the black kite, the peregrine falcon, the fan-tailed raven, the black-headed gull, the Eurasian hobby, the great cormorant, the greater Flamingo, the Great White Pelican, the Common Crane, the Grey Heron and the Eurasian hoopoe. In addition, there is the barn owl, Pharaoh's eagle-owl and the glossy ibis. (Reports by Swann (2001), Jansen (2001), Gochfeld (2015) and IBRCE (2023)).

The little owl, desert owl, and long-eared owl are all reported regularly farther north in Israel. Overall, this is a remarkably close fit for the proposed list of birds for Leviticus 11:13–19, and illustrates what might have been commonly found in the territory of the wanderings in a wetter climate.

Testing Across Time

We have evidence of a similar range of bird species from the Takarkori rock shelter, near one of the former lakes of the Central Sahara (Van Neer et al., 2020). These have mostly been radiocarbon dated to a period between 2350–3950 BC. The dating of these items must be prior to the final deserti-

Table III. Comparison of Aves species, Takarkori (Van Neer et al., 2020), Ancient Egypt (Wyatt and Garner, 2022) and Eilat 21st Century (Jensen, 2001; Swann, 2001; Gochfeld, 2015; and the International Birding and Research Center Eilat, 2023).

Takarkori – Aves Species Finds	No. of Birds	Ancient Egypt	Eilat Reports 2001–2023
Aythya cf. *fuligula* (cf. tufted duck)	1	√	√
Podiceps cristatus (great crested grebe)	5	√	√
Pelecanus rufescens (pink-backed pelican)	2	√	x
Pelecanus onocrotalus (great white pelican)	2	√	√
Pelecanus sp. (pelican)	10	√	√
Microcarbo africanus (long-tailed cormorant)	3	√	x
Phalacrocorax cf. *carbo* (cf. great cormorant)	1	√	√
Phalacrocorax sp. (cormorant)	1	√	√
Plegadis falcinellus (glossy ibis)	1	√	√
Plectropterus gambensis (spur-winged goose)	2	√	x
Pernis apivorus (European honey-buzzard)	1	√	√
Buteo sp. (buzzard)	1	√	√
Circaetus sp. (snake-eagle)	9	√	√
Accipitridae size *Milvus* sp. (cf. kite)	4	√	√
Accipitridae size *Circus aeruginosus* (cf. western marsh-harrier)	1	√	√
Accipitridae size *Circaetus* sp. (cf. Snake-eagle)	16	√	√
Accipitridae indeterminate. (raptors)	19	√ (many)	√ (many)
Falco cf. *subbuteo* (cf. Eurasian hobby)	1	√	√
Fulica atra (common coot)	7	√	√
Gallinula chloropus (common moorhen)	1	√	√
Otididae size *Ardeotis kori* (large bustard)	4	√	√
Columbidae (pigeon or dove)	3	√	√
Corvus cf. *albus* (cf. pied crow)	1	√	√
cf. *Hirundo rustica* (cf. barn swallow)	1	√	√
Unidentifiable bird	98		

fication of the region (if only because so many are wetland birds). This area now "has a hyper-arid climate and falls within the hottest Earth temperature isoline, with precipitation nearly absent" (Cremaschi, 1998, pp. 13–48). Figure 4 shows the Takarkori wadi area where the remains were found, as it looks nowadays.

Apart from the birds, there were large number of bones from various kinds of cattle, sheep, and goats, indicating a pastoralist culture. Evidence including human burials and animal bones shows an occupation in its later phase dated from around 3000–1500 BC (Biagetti and Lernia, 2013). Isotope analysis carried out on bovine remains from this late phase indicated a grazing diet of grasses more commonly found in dry ecosystems, suggesting these animals grazed during the period of climate change from humid to arid. Ovicaprids (domestic sheep and goats) gave values consistent with a generally mixed browsing diet including shrubs and trees. The latest human burial found at Takarkori was dated about 1200 BC (Lernia and Tafuri, 2013).

Table III lists bird remains (Aves species) at Takarkori and compares them with bird identifications from Ancient Egypt across a broadly contemporary period using hieroglyphs, bone remains, mummies, and art (Nilsson et al., 2020; Wyatt and Garner, 2022). The final comparison is with the bird reports from Eilat during the 21st century. What this shows is that the same birds discovered at Takarkori were also known in Ancient Egypt and can now be seen at Eilat, giving a continuity of some 4,000 years for these species across the wider region.

This is a remarkable set of findings, and powerful evidence for an African Humid Period environment which supplied grass for grazing animals and sufficient trees for tree nesting wetland birds such as the ibis and cormorant.

According to Their Kind

In the Leviticus list, four birds are qualified with the attribution *min* (מין as in *laminah*, למינה “according to their kind”). This applied to bird 4, *ayah* = Falcon, bird 6, *'orev* = Raven, bird 10, *nets* = Hawk, and bird 19, *'anaphah* = Heron. This is accepted as a taxonomic guide, but, as Angelini and Nihan (2020, p. 48) note:

> Accordingly, we should not expect that the division of animals (including birds) into species would consistently follow the divisions established in modern zoology.

The Eurasian hobby which produced a strong OP correlation with *nets* and was proposed as a “hawk” is now classified among the *Falconidae*. Also, while the ancient Egyptians clearly recognized the falcon as a distinct type of raptor, the Greeks and early Romans did not. The reports from Eilat mentioned above are helpful in showing what similar birds to these four have been reported there, indicating how ancient Hebrew taxonomic concepts might align with modern taxonomies:

1. Falcon—lead bird, peregrine falcon. Other Falconidae reported at Eilat excluding the Eurasian hobby are the red-footed falcon, Eleonora’s falcon, Barbary falcon, common kestrel, and the lesser kestrel.

Figure 5. Griffon Vulture observed over Andalusia (Spain) © Martin Johnson.

2. Raven—lead bird, fan-tailed raven. Other Corvidae reported at Eilat are the brown-necked raven, house crow, and hooded crow.
3. Hawk—lead bird, Eurasian hobby. Other Accipitriformes smaller than eagles but excluding falcons and kites reported at Eilat were the Eurasian sparrowhawk, Eurasian goshawk, Levant sparrowhawk, western marsh harrier, hen harrier, Montagu’s harrier, pallid harrier, common buzzard, crested honey buzzard, long-legged buzzard, steppe buzzard, and the European honey buzzard.
4. Heron—lead bird, grey heron. Other Heronidae reported at Eilat were black-crowned night heron, western reef heron, squacco heron, striated heron, purple heron, western cattle egret, great white egret, little egret, and the bittern.

The chief problem with this approach is that other birds on the list not given *min* attributions have been reported together with several other related species which would suggest that they too should have been given a *min* attribution, if conformity to modern bird taxonomies lies behind the hypothetical Hebrew taxonomic concept above.

A clearly contradictory example is bird 9, *shachaph* = Black-headed Gull. This has been seen at Eilat alongside ten other species of gull, making it more abundant in terms of similar species than the Falconidae, Corvidae, or Heronidae known in the region, yet there is no *min* attribution for this bird in either the Leviticus or Deuteronomy lists.

A possible explanation could be that the gulls might have been regarded then as different varieties of the same bird, much as we nowadays classify all the scores of different varieties of domestic chicken as the same sub-species (G*allus gallus domesticus*), just varying in size and plumage.

This explanation could easily apply also to the eagle and vulture species listed above. Both eagles and vultures are typically spotted flying at height, and against a bright sky only a silhouette can be seen with the naked eye. The silhouettes of the five eagles listed above are practically identical, but distinguishable from the silhouettes of the six vulture species found in the region (Jonsson, 1999, pp. 146–151, 124–127; Porter and Aspinall, 2010, pp. 78–83, 92–94).

The griffon vulture in Figure 5 can only be identified as such because of the known existence of large flocks of those birds at the location where the photograph was taken (north of Ronda, Andalusia, Spain). The plumage colors which distinguish it from the other vulture (the cinereous vulture) native to Spain are not visible in these conditions.

On this basis, the Hebrew taxonomy might only recognize one eagle and one vulture, with minor variations of size and plumage colors not regarded as relevant. The Heronidae on the other hand are of significantly different shapes and sizes, but have in common that they occupy the same habitats, and all fly with their heads held back, their necks in an “S” shape. This feature alone distinguishes them from cormorants, cranes, and flamingos. These considerations simply show that a better understanding of ancient Hebrew bird taxonomies could be developed by considering a range of factors.

Conclusion

Paleoclimate evidence shows that from the Sahara across to northwest Saudi Arabia before around 1250 BC, very different climate conditions prevailed than subsequently. What is now arid desert was once savannah, with widespread tree coverage, while high rainfall in the mountain regions will have produced extensive wetlands on the lower ground, especially in the Sinai drainage area of the Wadi El-Arish. People grazed domestic animals all across this area, and certainly in the Negev highlands, until the climate changed to arid, and the land became desert.

All the "banned birds" of Leviticus 11:13–19 could have been found in the wetlands and the adjacent landscapes (savannah, woodland, desert, mountain, etc.) typical of the Middle and Late Bronze Age humid period in the central Sinai. This forms a precise fit for the habitats of the listed birds (see Table II) in a close proximity that would be difficult to match elsewhere in the territory shown in Figure 1.

This grouping of birds points directly to a set of climate and environmental conditions that can be identified over a specific period of time which includes the traditional dating of the wilderness narrative. The lack of precision of the various dating methods, coupled with the uncertainties about the speed of onset of desertification coupled with a major change in climate means we can suggest that these conditions pertained between the 18th and 13th centuries BC.

These findings are supportive of the Leviticus 11:13–19 list of "banned birds" reflecting an accurate historical and geographical account of conditions in the Sinai during the middle of the 2nd millennium BC. This supports the view of Soggin (1984, pp. 19–20) that the "wilderness tradition" contains accurate historical records, and also that of Hoffmeier (2005, pp. 167, 209), as supplementary internal evidence pointing to the wandering locations being in the Sinai.

On the other hand, it is hard to support the arguments of Finkelstein and Silberman (2002) which requires that writers in a farming community some seven to nine centuries later could have come to associate this specific set of birds with the "wilderness tradition." This is because by that time the whole of Sinai had been arid desert for several centuries, and most of these birds would be absent from that location because of the destruction of most of their habitats following climate change.

Further research using ornithological data could explore the reasons for these birds being banned, and a review of possible taxonomies.

Summary

1. The list of "banned birds" in Leviticus 11:13–19 appears to preserve an accurate reflection of a very different set of climate conditions than has prevailed in the relevant territory for the past three millennia. This list shares many birds in common with those found in the ancient Sahara and ancient Egypt when the climate in those locations was much wetter, as well as with modern Eilat which provides a microcosm of those conditions.
2. Comparisons of paleoclimate evidence shows that wetter climate conditions in the Sinai and Negev prevailed across the middle of the 2nd millennium BC, the traditional time of the Exodus.
   a. The major change in climate conditions in the late 2nd millennium BC coupled with the desertification of the Sinai Peninsula and neighbouring territories makes late authorship theories for Leviticus untenable.
   b. Both the identifications of the "banned birds" and their habitats, and the basic requirements of "flocks and herds" for food and water make the leap of supposed imagination by the hypothesised late authors hard to conceive.
   c. There is no point banning birds from being eaten by people who are most unlikely to come across such birds.
3. The Sinai and neighbouring Negev region provided adequate conditions for a large pastoralist group such as the Israelite tribes following the Exodus, making it unnecessary to propose other areas such as northwest Saudi Arabia for the territory of the wanderings.
   a. The evidence in support of a Sinai location for the wanderings of the Israelites supports arguments for the "Red Sea" crossing taking place on the west side of Sinai.
   b. The evidence of the desert kites shows that pastoralist groups once occupied the relevant areas, though the builders of them remain unknown.
   c. The Israelites themselves may have contributed to the desertification of the Sinai and Negev by grazing their animals and cutting trees for firewood.
4. The "*-min*" attributions in Leviticus 11 and Deuteronomy 14 point to a very different system of taxonomy for birds than is used at present. It seems possible that birds were

classified according to shape and size, and possibly behaviours and habitats.

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Letters to the Editor

Sources of Belt Basin Sediments and Metasediments

Michael Oard (*Creation Research Society Quarterly* 61(1):16–31, 2024) speculates regarding the source of the sedimentary and metasedimentary rocks comprising the upper Precambrian Mesoproterozoic Belt-Purcell Supergroup of the Belt Basin in northwest USA and southwest Canada (Figure 1). The Belt Basin sediment and metasediment accumulation, which Oard notes "…represents one of the thickest Precambrian sedimentary basins in North America…", is up to 20-km thick and comprises fine-grained, siliciclastic mudstones, dolomitic and sandy mudstones, limestones, silty limestones, dolomites, sandy dolomites, and minor sandstones.

Noting that most paleocurrent data in the Belt Basin sediments indicates that sediment flow was predominantly from the southwest and west, Oard notes that some uniformitarian workers conclude that a continental mass existed to the west of the Belt Basin (Evans et al., 2000). Oard suggests three possibilities regarding a western source of sedimentary components, viz.: (1) "…another continent…before Noah's Flood to the west…"; (2) "…an uplifted Pacific Ocean basin?"; and (3) an "…impact to the west…."

Oard notes that many creationists assign deposition of Precambrian rocks to Creation Week (Dickens and Snelling, 2008; Dickens, 2018) or the Antediluvian period (Humphreys, 2014) and questions "…*how such a large volume of sediment was deposited in a very deep "hole" before the Flood?*" Noting that the contact between the Belt Supergroup and the overlying Cambrian Flathead Sandstone, which he designates as Flood-deposited, is conformable, Oard interprets this as evidence that the Upper Precambrian Belt Basin rocks were deposited early in the Flood. Oard suggests the difficulty in detecting disconformities and paraconformities, and the rarity of angular unconformities in the Belt Basin sedimentary rocks, indicates the basin subsided and filled quickly, and asks; "…*what could generate so much sediment so quickly*?" Uniformitarian workers (Parker and Hendrix, 2022) have also inferred high rates of sediment accumulation in the Belt Basin.

Very rapid extrusion of clastic and chemical components of sediments, and copious water from the Earth's mantle, could generate large volumes of sediment very quickly (Figure 2). The Belt Supergroup sediments were probably extruded from the mantle on the Canadian Shield and other Precambrian provinces and deposited very quickly from Day 1 to Day 40 of the Flood. Such a scenario is outlined below in a gravitational decompression-recompression Flood model. Hirtz et al. (2024) recognized "…fundamental uncertainties in the depositional age and sediment provenance record of the Belt-Purcell Supergroup." in northwestern USA and southwestern Canada. Noting that little emphasis has been focussed on ancestral North American sediment sources, they used detrital zircon U-Pb geochronological data of Belt Basin sediments to determine sediment source areas on the North American continent. Noting "…widespread preservation of zircon grains generated during orogenesis…" they acquired 2,593 U-Pb ages from 27 samples covering all stratigraphic units of the northeastern Belt Basin. They then compared their Belt Basin geochronologic data set to detrital zircon ages from some 22 potential source areas on continental North America.

They determined that all potential sediment source areas to the north, northeast, and east of the Belt Basin are on the Canadian Shield. Source areas directly east of the Belt Basin comprise the Archean/Proterozoic Medicine Hat Block, the Archean Wyoming Craton, and the Archean Superior Craton and Abitibi greenstone belt on the Canadian Shield. Potential source areas to the south and southeast comprise several Precambrian sources including the Proterozoic Mazatzal, Yavapai, and Mojave provinces. They determined that "Variations in sediment provenance are expressed by three distinct intervals within the Belt-Purcell Supergroup." They also interpreted a complex provenance record for the middle Belt Supergroup succession as evidence for

> "…rapid episodes of drainage reorganization and/or competing pulses of siliciclastic input from the southern provinces, Canadian Shield, and a potentially unidentified source" and "…a continental-scale shift in sediment provenance from the Canadian Shield to the southern provinces…" which was "…punctuated by several instances of drainage instability…." (Hirtz et al., 2024)

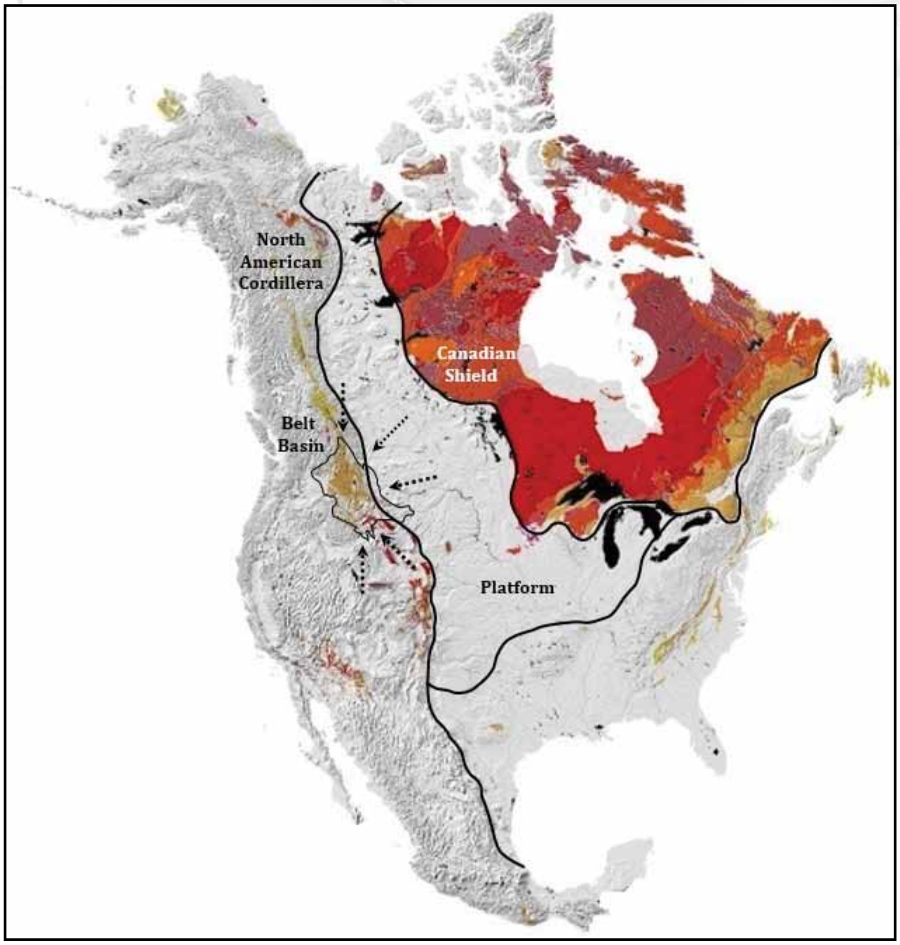

Figure 1 ***(left)*****. Major tectonic elements of North America showing the Belt Basin in northwest USA and southwest Canada and postulated sediment flow directions (dashed lines) determined from geochronological analysis of Belt Basin detrital zircons (Hirtz et al., 2024).**

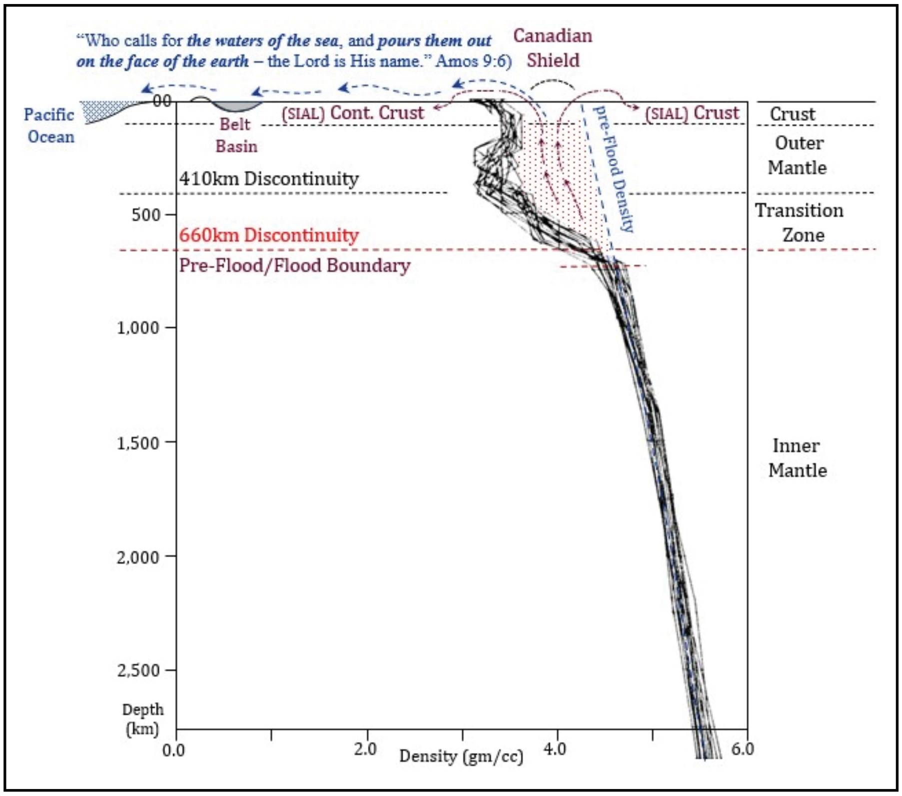

Figure 2 ***(lower left)*****. Density profiles through the Inner Mantle–Transition Zone–Outer Mantle–Crust (After Press, 1970). Reduced density above the 660-km Mantle Discontinuity is due to the expulsion of material (red-shaded) from the mantle outward toward the Earth's surface to form the continental crust during the Genesis Flood.**

Such episodes of "…drainage reorganization" and "…drainage instability…" might explain variations in paleocurrent directions observed in the Belt Basin sediments. Faulting and thrusting in the North American Cordillera may have raised temporary barriers to the west of the Belt Basin, causing west-to-east flow of mantle-derived sediment from the Canadian Shield and other provinces.

Figure 2 shows a family of density profiles through the Inner Mantle, Transition Zone, and Outer Mantle throughout the globe. The pronounced density reduction above the 660-km Mantle Discontinuity is interpreted to be the result of a major event at some time in Earth's history. Some researchers have suggested that the density increase with depth through the Outer Mantle and Transition Zone (Figure 2) is much more rapid than can be explained by the self-compression of homogeneous material within the Earth's gravitational field. Some have suggested that the mineralogical phase changes throughout the Transition Zone occurred from the deeper higher-pressure, higher-density phases to the shallower lower-pressure, lower-density phases, due to a decrease in gravitational force over time. Liu (1979) for instance has suggested"Velocity gradients in the region between about 350 and 900 km in depth (the transition zone) are far greater than those expected due to self-compression and thermal expansion of the mineral phases in the upper mantle." (Liu, 1979, p. 178)

Dearnley (1966) wrote regarding phase changes in the Earth's mantle, suggesting

> A decrease in pressure…would promote such *phase conversions from the high-pressure to the low-pressure forms resulting in an increase in volume*…. the upper part of the lower mantle and the upper mantle were characterized by the high-pressure phases…the changes having resulted in *an expansion of at least the outer portions of the Earth.* (Dearnley, 1966, p. 35. Emphases added)

In a gravitational decompression-recompression Genesis Flood geologic model (Hunter, 2004, 2020, 2022) the Genesis Flood cataclysm is perceived as being initiated by a temporary reduction of gravitational force. The model is based on two reasonable assumptions viz.: (1) given that God created gravitational force, He would be well able to change it if and when required; and (2) the temperature of the created Earth's interior, at least in part, was just below its melting temperature (*sub-solidus*), and water-saturated. The model is, I believe, supported by Scripture and by evidence in the Solar System and the wider Universe. Decompression of the Earth on Day 1 of the Flood cataclysm was probably affected by an increase in the value of the exponent of the separation distance in the Universal Gravitational Law. Decompression initiated adiabatic decompression melting and viscosity reduction of mantle material above the 660-km Mantle Discontinuity. Amos 9:5, "*The Lord God of hosts, He who touches the earth and it melts*…" (NKJV), may be a Scriptural reference to this phenomenon.

Because mantle melting and viscosity reduction was affected by decompression, no heat input or temperature rise was required to effect melting. Buoyancy of magma, due to the density contrast between molten magma and adjacent mantle material, caused molten magma to rise and be extruded at the Earth's surface, most notably in the Precambrian shield areas. Philpotts and Ague (2022) note that reduction of mantle viscosity is primarily due to removal from the mantle of polymerizing, tetrahedrally coordinated SiO_2, $KAlO_2$ and $NaAlO_2$ groups. The silica and alumina removed from the mantle is now incorporated in the granitic siliceous/aluminous ("SIAL") outer layer of the continental crust (Figure 2).

The Precambrian rock record, including the Belt-Purcell sediments, and copious mantle-derived water ("…*the fountains of the great deep*"—Gen. 7:11) were extruded onto the Earth's surface, on the Precambrian cratons and shields During Day 1 to Day 40. Amos 9:6, "*Who calls for the waters of the sea, and pours them out on the face of the earth—the Lord is His name.*" (NKJV), may be a Scriptural reference to this phenomenon. The provenance data of the Belt Basin sediments indicates that some mantle material may have been extruded through other Precambrian provinces such as the Medicine Hat Block and Wyoming Craton to the east, and the Mazatzal, Yavapai, and Mojave provinces to the south and southeast.

Earth radial expansion of approximately 100 km occurred due to density reduction above the 660-km Mantle Discontinuity (Figure 2). Amos 9:5, "*All of it shall swell like the River*, …" (NKJV), may be referencing this Earth-expansion phenomenon. Birch (1968) notes that

> If the upper 600 km of the mantle, …were converted to the high-pressure forms of the lower mantle, with a 20- percent increase of density, the shrinkage would be about 5 percent of the whole volume or *a radial decrease of about 100 km*. (Birch, 1968, p. 146. Emphasis added)

Partial restoration of gravitational force on Day 40 significantly inhibited mantle differentiation and exsolution of mantle water. Full restoration of gravitational force on Day 150 caused newly formed, dense, basaltic oceanic crust to subside to form the ocean basins, into which the Flood waters then flowed. This recompression caused some Earth contraction, perhaps referenced in Amos 9:5, "*And subside like the River of Egypt*" (NKJV). Because solidification of the mantle and consequent shutdown of mantle differentiation was achieved by recompression, no removal of heat or reduction of temperature was required.

We might reasonably assume that the "…*wind*" which, on Day 150, God caused "…*to pass over the earth*" (Gen. 8:1), passed over the whole globe. This Day-150 phenomenon occurred because on Day 1 of the Flood cataclysm, the hydrostatic equilibrium of the atmosphere was disrupted due to the reduction of gravitational force, causing the troposphere to move outward away from the Earth's surface. Full restoration of gravitational force on Day 150 restored the hydrostatic equilibrium of the atmosphere, causing the troposphere to descend back down toward the Earth's surface, causing the "…*wind*" …to "…*pass over*…" the entire globe surface.

If the Belt Basin sediments were sourced from the mantle, on the Canadian Shield and other areas, then no pre-Flood continent to the west, no uplifted Pacific Ocean basin, and no impact to the west are required as sediment sources.

Maxwell J. Hunter

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Response to Hunter

I welcome Max Hunter's letter and this chance to add a few more details to the analysis of the amazing Belt-Purcell Supergroup strata from my recent paper (Oard, 2024). The Hirtz et al. (2024) article came out after I had sent in my paper. I found the article very interesting.

First of all, the vast majority of the sedimentary rocks in the Belt-Purcell Supergroup are argillite, siltite, and quartzite with a minor amount of carbonate and diabase sills. Secondly, I did not suggest that the sediments came from exotic continents to the west; I was simply listing the very divergent *uniformitarian suggestions*, since most paleocurrent and other features indicate a source from the west to southwest, which is still true.

I noted that the thorough research by Hirtz et al. analyzing zircons and their providences was from the *northeast perimeter* of the Belt-Purcell Supergroup in Glacier and Waterton Lakes National Parks. The strata in this location are thinner, only 4.5 km thick, compared to at least 20 km in the western Belt Basin. There is reason to believe that the original Belt Basin was on the order of 25 to 30 km deep and around 400 km in diameter before it inverted (uplifted). This is based on the billions of well-rounded quartzite cobbles and boulders with percussion marks that have been spread up to 1,200 km east to east-northeast into central Saskatchewan, southwest Manitoba, and western North Dakota (Oard et al., 2005) and west about 400 km to the Pacific Ocean (Oard et al., 2006). Since the quartzite is a metamorphic sandstone formed under greenschist metamorphism, 300°C–450°C, that eroded from the top of the Belt-Purcell Supergroup during vertical uplift, there must have been around 5–10 km or so of additional strata on top of what is left today. In fact, Bedrosian and Box (2016, p. 312) claim the Belt Supergroup is still 30 to 35 km thick in northwest Montana and adjacent Canada, even reaching the Moho in places.

Hirtz et al. (2024) made a strong case that the sediments from the northeast periphery, likely from the lower Belt strata, came from the east northeast, some as much as 3000 km away! This is also acknowledged by Slotznick et al. (2016, p. 234):

> Sediment provenance studies suggest a predominantly western source for the lower two thirds of Belt Strata, with a predominantly Laurentian source observed in Glacier National Park and the Helena Embayment [eastern edge].

Hirtz et al. (2024) go on to say that the middle portion of the Belt had variable east-to-south directions, while the top of the Belt, the Missoula Group, overwhelmingly originated from the south. Regardless, the thickest part of the Belt Supergroup is the lower Belt in the western and central Belt Basin, and it came predominantly from the west. Even Hirtz et al. (2024, p. 1137) acknowledge the western source for most of the lower Belt:

> The fine-grained clastic sediments are attributed to exotic western sources on the basis of isopach thicknesses, paleocurrent data (Cressman, 1989), and DZ [detrital zircon] ages that demonstrate the presence of non-North American grains…

The source of sediments from the west is still unknown.

The pattern of sedimentation is close to what I would expect if the Belt Basin was an impact crater (Oard, 2013, 2024). The initial filling of the crater would come from *all* directions. In other words, sediments on the northeast edge would come from the northeast. The fact that the sediment came from as far away as 3000 km testifies to the enormous catastrophism occurring at the time, which I place very early in the Flood.

Further evidence that the Belt basin is a filled impact crater is the huge, roughly saucer-shaped depression on the western edge of the North American craton. It is too wide to be a rift (Oard, 2009). Conventional scientists have no mechanism to explain cratonic basins (Oard, 2009). Among many problems is, what would cause the deep subsidence in the continental crust (Oard, 2013)? It is unlike another rift that is about as deep, the Midcontinent Rift. It is quite narrow in shape: 2,200 km long, over 100 km wide in places, and up to 30 km deep (Reed et al., 2025).

The Belt Basin filled very fast, and I agree with Hunter on the timing between Day 1 and Day 40, although I believe closer to Day 1. During the Recessional Stage of the Flood (Walker, 1994), the basin inverted with the top eroded by Floodwater.

Hunter suggests such a massive amount of sediment rapidly deposited in water could only come from the Earth's mantle in his model. I agree that a powerful mechanism is required for all the geological work. But I suggest that multiple impacts very early in the Flood could generate the sediments, pulverize them into fine grains (as observed), form the Great Unconformity, and provide extremely fast, turbulent currents to transport the sediments, even from as far away as 3000 km.

Carl Froede and I have already made some brief comments on Hunter's Flood mechanism (Froede and Oard, 2007; Oard and Froede, 2009; Oard, 2023). I will just add one further comment. It seems like Hunter's decompression/compression mechanism of a decrease in gravity very early in the Flood with the rock above the 660-km Mantle Discontinuity *expanding by 100 km* and then recompressing back later in the Flood to its original gravity would have many severe geophysical consequences that should be detected.

Michael J. Oard

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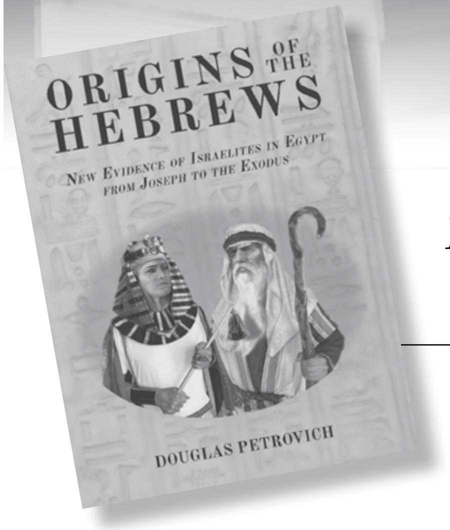
Media Reviews



Origins of the Hebrews: New Evidence of Israelites in Egypt from Joseph to the Exodus

by Douglas Petrovich

New Creation, Nashville, TN, 2021, 314 pages, $39.99

Israel's Sojourn in and Escape from Egypt

According to the Bible, Jacob (Israel) left the land of Canaan and came to Egypt with his family and lived and died there. His descendants continued to live there for 430 years until God used Moses to bring them all out by many miraculous signs. Moses continued to lead his people through the wilderness to the land of Canaan. Eventually the Israelites went into Canaan, conquered it, and settled there.

Is this account real history, or is it just legend or myth? Biblical evidence that the account is meant to be taken literally includes the fact that the account was written as narrative, not as poetry. Also, God instructed His people to have a yearly remembrance of this marvelous deliverance, which they do until this day. In addition, throughout the Bible these events are often referred to and they are always treated as real history (see Deuteronomy 26:5–8).

However, most modern scholars believe there is no archaeological evidence for any of this and therefore conclude that the entire account is unhistorical or mythical. One would expect that there would certainly be much physical evidence if the Hebrews had indeed spent 430 years in Egypt and then left when their number had increased to likely at least two million people (according to Numbers 1:46, the number of adult males who left was 603,550, but this did not include members of the tribe of Levi, nor women and children).

In *Origins of the Hebrews*, Douglas Petrovich presents an overwhelming number of archaeological discoveries favoring the Biblical narrative. He carefully marshals his evidence and scrupulously interprets it. He analyzes contrary interpretations to his theory in great detail and concludes that they are severely lacking. Those interested should read the book for Petrovich's analyses of other interpretations since they are too voluminous to address in a short review of the book. This book is not for casual reading; it requires intense concentration to follow the author's reasoning. But the rewards are exciting as the reader learns of numerous discoveries which clearly point to the Bible's account being the only reasonable explanation for them.

Petrovich is qualified for this endeavor, having earned an M.A., Th.M., M. Div., and a Ph.D. with a major in Syro-Palestinian archaeology and a first minor in ancient Egyptian language (hieroglyphics). His book includes a detailed table of contents, very helpful appendices which I often referred to (keeping a bookmark there was helpful), several quality figures all in a section after the appendices, references (I counted 446), an ancient writings index, and a general index.

A major source of the problem in finding archaeological attestation to the Biblical account is that Genesis 47:11 tells us that Jacob's family settled in the part of Egypt referred to as Rameses. However, there is no evidence of Israel being in Egypt during the reign of Rameses. But, using Biblical chronology, Petrovich calculates that the Hebrews would have actually been in Egypt many years earlier, during the reign of Sesostris III. During this time, the area later called Rameses was known as Avaris. So why does the Bible state the place was called Rameses? Petrovich explains that this would have been due to a scribe, who copied the Scriptures, updating the name so that his contemporary readers would recognize the location. Another example of this would be how in Genesis 14:14 we read that Abraham traveled to Dan to rescue his nephew, Lot, and others. But in Joshua 19:47, we are told that the children of Dan smote Leshem and renamed it "Dan," well after Moses died (Joshua 1:1,2). So, Cecil B. DeMille's epic film, The Ten Commandments, with Yul Brynner playing Rameses, was mistaken regarding the identity of the pharaoh.

There is much evidence of the Israelites living in Egypt! How strong is the archaeological case for the Biblical account of the Hebrews in Egypt? Although there is little in the way of written accounts by the Egyptians, the archaeological discoveries are compelling. There is far too much circumstantial evidence to be the result of a multitude of coincidences. How likely would it be for all the following events to have happened in ancient Egypt at the precise time that the Bible indicates they did?

- Canaanite type buildings built in the Land of Goshen (Avaris)
- A larger-than-life statue of a Canaanite type person there
- A leader of the workers named "He-who-was-disfavored" who was the brother of the leader of these Canaanite people, corresponding to Joseph's elder son, Manasseh, who was disfavored when his grandfather, Jacob, blessed him and his brother, Ephraim
- "He-who-was-disfavored" having a son named Shekem, just as Manasseh did
- Huge numbers of large silos built in Egypt, which would have been needed to store all the grain harvested during the seven years of plenty
- The nomarchs (powerful governors) disappeared from Egypt since they would have sold their land to pharaoh during the seven years of famine
- The priests keeping their land, in agreement with the Biblical narrative
- Skeletons of yearling sheep and goats found in Avaris—the first Passover
- Queen Hatshepsut abdicating shortly after the Israelites left—she was likely the daughter of Pharaoh who retrieved the baby Moses from the Nile
- The pharaoh at the time the exodus would have happened being preceded by a pharaoh whose reign exceeded 40 years
- The pharaoh at the time of the exodus not being the first born, or else he would have died in the tenth plague
- The pharaoh at the time of the exodus destroying the gods of Egypt, since they were helpless against the God of the Israelites
- The pharaoh at the time of the exodus doing everything in his power to eliminate the remembrance of a former queen who would have been the right age to have rescued Moses from the Nile River
- The pharaoh at the time soon after the exodus conducting a military campaign in which not riches, but an enormous number of slaves were captured, much more than at any other time in Egyptian history which could have been an effort to replace the Hebrew slave population which had departed
- The Egyptian superpower ceased from all their conquering military campaigns and resorted to making treaties, which could have been due to Egypt's army having perished in the Red Sea

In over two hundred pages of detailed text, there are bound to be some errors and typos, especially in this first edition. I found a reference to the wrong figure, an incorrect Scripture reference, incorrect compass directions, and various typos. However, none of these errors in any way detracts from any of Petrovich's points. I hope that he makes a revised edition because his book presents an overwhelmingly powerful case for the truth of God's Word regarding the origin of the Hebrews.

Arthur Manning

Instructions to Authors

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Hitchcock, A.S. 1971. *Manual of Grasses of the United States*. Dover Publications, New York, NY.

Walker, T.B. 1994. A biblical geologic model. In Walsh, R.E. (editor), *Proceedings of the Third International Conference on Creationism* (technical symposium sessions), pp. 581–592. Creation Science Fellowship, Pittsburgh, PA.

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Creation Research Society

History—The Creation Research Society was organized in 1963, with Dr. Walter E. Lammerts as first president and editor of a quarterly publication. Initially started as an informal committee of 10 scientists, it has grown rapidly, evidently filling a need for an association devoted to research and publication in the field of scientific creation, with a current membership of over 600 voting members (graduate degrees in science) and about 1000 non-voting members. The *Creation Research Society Quarterly* is a peer-reviewed technical journal. It has been gradually enlarged and modified, and is currently recognized as one of the outstanding publications in the field. In 1996 the *CRSQ* was joined by the newsletter *Creation Matters* as a source of information of interest to creationists.

Activities—The Society is a research and publication society, and also engages in various meetings and promotional activities. There is no affiliation with any other scientific or religious organizations. Its members conduct research on problems related to its purposes, and a research fund and research center are maintained to assist in such projects. Contributions to the research fund for these purposes are tax deductible. As part of its vigorous research and field study programs, the Society operates the Van Andel Creation Research Center in Glendale, Arizona.

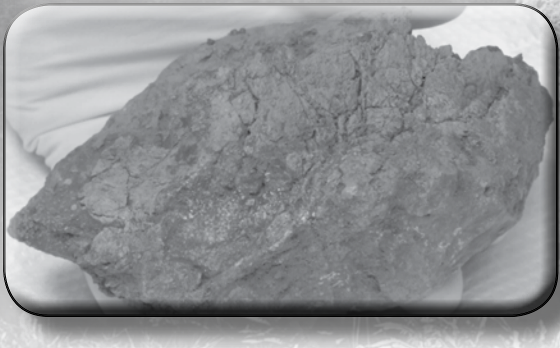
Membership—Voting membership is limited to scientists who have at least an earned graduate degree in a natural or applied science and subscribe to the Statement of Belief. Sustaining membership is available for those who do not meet the academic criterion for voting membership, but do subscribe to the Statement of Belief.

Statement of Belief—Members of the Creation Research Society, which include research scientists representing various fields of scientific inquiry, are committed to full belief in the biblical record of creation and early history, and thus to a concept of dynamic special creation (as opposed to evolution) both of the universe and the earth with its complexity of living forms. We propose to re-evaluate science from this viewpoint, and since 1964 have published a quarterly of research articles in this field. *All members of the Society subscribe to the following statement of belief:*

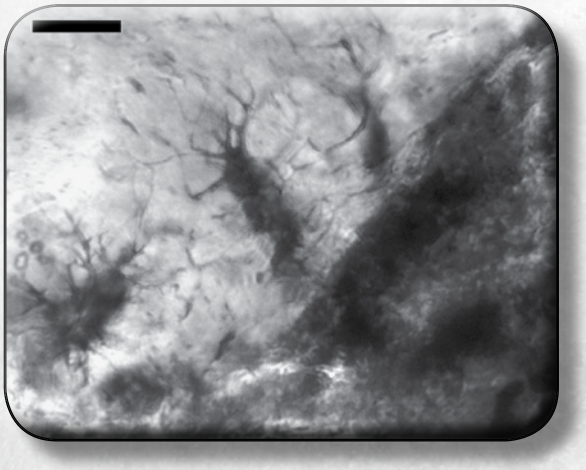
1. The Bible is the written Word of God, and because it is inspired throughout, all its assertions are historically and scientifically true in all the original autographs. To the student of nature this means that the account of origins in Genesis is a factual presentation of simple historical truths.
2. All basic types of living things, including humans, were made by direct creative acts of God during the Creation Week described in Genesis. Whatever biological changes have occurred since Creation Week have accomplished only changes within the original created kinds.
3. The Great Flood described in Genesis, commonly referred to as the Noachian Flood, was a historical event worldwide in its extent and effect.
4. We are an organization of Christian men and women of science who accept Jesus Christ as our Lord and Savior. The act of the special creation of Adam and Eve as one man and woman and their subsequent fall into sin is the basis for our belief in the necessity of a Savior for all people. Therefore, salvation can come only through accepting Jesus Christ as our Savior.

iDINO II

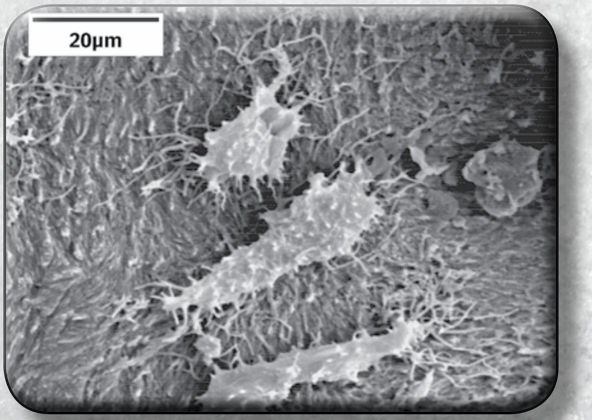
Investigation of Dinosaur Intact Natural Osteo-tissue



A fragment of the *Triceratops* brow horn. Fragments, such as this one, still contain tissue and cells.



Microscopic examination of tissue extracted from a *Triceratops* horn reveals bone cells still present.



Electron microscope picture of intact bone cells still in tissue extracted from a *Triceratops* horn.

How can pliable, stretchable tissue survive inside dinosaur fossils for over 65 million years?

How can this tissue still contain intact cells and even dinosaur proteins?

How can this fragile biological material survive for so long?

The answer to these questions directly challenges the current, evolutionary-biased, geologic timescale.

The Creation Research Society began its iDINO research initiative for the purpose of studying soft tissue in dinosaur fossils. The first phase of the project detected pliable, unfossilized tissue in a brow horn of a *Triceratops*. Within this tissue were intact osteocytes (bone cells). Some results from the iDINO project have been published in a technical microscopy journal and presented at an international microscopy conference. The Spring 2015 issue of the *Creation Research Society Quarterly* also features a special report of the iDINO project. Plus, to further spread the important information about soft tissue, the Society is developing a video (Echoes of the Jurassic).

The **second phase** of the project (iDINO II) will look more extensively at the process of tissue preservation. Evolutionists have offered various theories of how this tissue could survive for millions of years. iDINO II will methodically investigate these preservation claims, assessing their plausibility.

The iDINO results have already provided a strong challenge to the evolutionary worldview. More extensive and detailed examination may provide even stronger evidence that the age of dinosaur fossils is far less than 65 million years. To this end, the Society continues to seek those willing to fund this project with either one-time gifts or monthly donations.

For more information contact us at (928) 636-1153 or crsvarc@crsvarc.com.

Also visit http://tinyurl.com/nphm2c4 for project updates and details.

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