

AGE OF THE ARIZONA METEOR CRATER

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Abstract

The Arizona Meteor Crater is the best preserved and also the most studied impact event on the earth. This large crater, about 1200 meters wide and 175 meters deep, is located in the desert plains of North Central Arizona. The crater penetrates Kaibab limestone and Coconino sandstone layers of Permian age. For many years there was lively debate over the origin mechanism, whether volcanic or impact. Other still-lingering questions concern the location and size of the actual meteorite, assuming impact, and also the time of the event. Date-of-origin evidence, the main emphasis of this paper, includes dendrochronology, rock erosion, radioactivity, and thermoluminescence. Published results have varied drastically between 800-200,000 years ago for the crater's time of formation. This study critiques the various chronology estimates, illustrating the inherent uncertainty of dating techniques.

Introduction

The Barringer Crater, located in northern Arizona, is familiar to many readers. This large depression averages 1200 meters (about 4,000 feet) in diameter; the crater floor lies 175 meters (570 feet) below the rim. It was first explored and publicized by prospectors a century ago; Hopi Indians living in the area were familiar with the crater much earlier. The crater has had many titles over the years:

- Crater Mountain
- Franklin Hole
- Coon Mountain
- Coon Butte
- Crater Mound
- Crater Mountain
- Canyon Diablo (Devil's Canyon)
- Meteor Butte
- Barringer Meteor Crater
- Arizona Meteor Crater

The last term, most common, is actually a misnomer. Meteors by definition disintegrate in the air rather than impacting the ground; it is *meteorites* that contact the earth and sometimes cause craters. A century ago when the crater was named, the distinction between meteors and meteorites was not made. In fact, the Barringer Crater was the first site recognized on earth as an impact from a space object. It remains the best known and most studied crater on earth. In the 1960s the Apollo astronauts trained at this lunar-like site.

Geologic Setting

The Barringer Crater is located in semi-arid North-Central Arizona, 40 miles southeast of Flagstaff and 20 miles west of Winslow (Figure 1). The site is also just 100 miles east of the CRS Van Andel Research Center. Northern Arizona is the southern part of the Colorado Plateau which covers 150,000 square miles, stretching through several southwestern states. This region is characterized by flat-lying sedimentary rock, relatively high elevations (5,000-11,000 feet), and occasional uplift and erosion.

The Barringer Crater penetrates sedimentary rocks of Triassic and Permian age. First intersected are 9-12 meters (30-40 feet) of Moenkopi reddish brown sandstone/siltstone (Figure 2). Beneath this formation, the impact pulverized a 76 meter (250 foot) layer of Kaibab Limestone and a 2 meter (6 foot) underlying layer

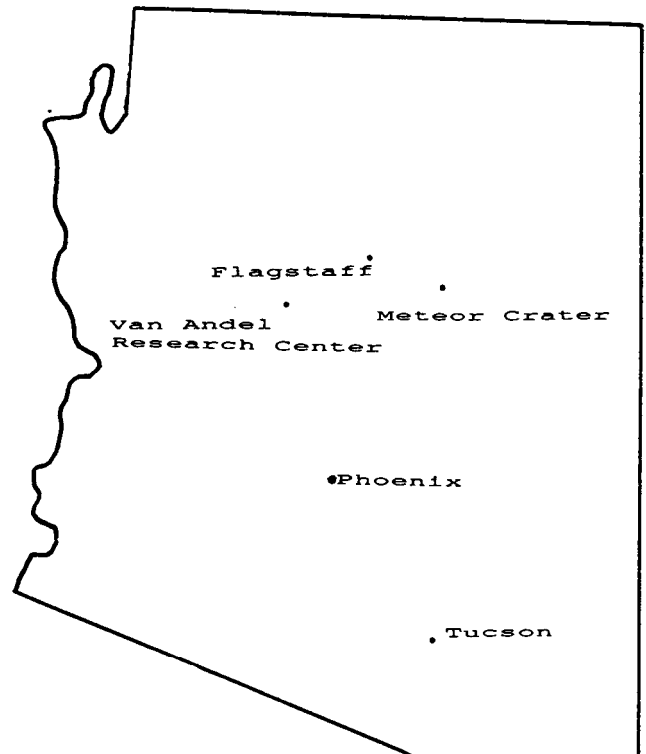


Figure 1. A map of Arizona, showing the location of Meteor Crater and also the Van Andel Research Center.

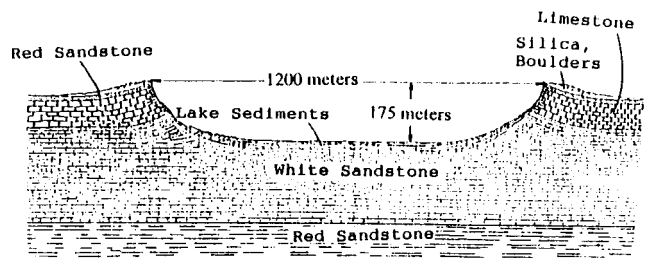


Figure 2. Vertical section through Barringer Crater (Fairchild, 1907). In sequence, from top to bottom, the sedimentary layers are:

- Moenkopi (red) sandstone, 9-12 meters
- Kaibab or Aubrey limestone, 76 meters
- Toroweap sandstone, 2 meters
- Coconino (white) sandstone, 305 meters
- Dark red sandstone, undisturbed

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of Toroweap sandstone. Finally, the impact fractured 76 meters (250 feet) of Coconino Sandstone, which totals about 305 meters (1,000 feet) thick. These same rock layers also occur in the upper exposed portions of the Grand Canyon. Millions of tons of sandstone and limestone were instantly excavated during the meteorite collision. Around the crater edges, 7,000 ton blocks of stone are tossed and overturned. The total energy of the impact is estimated at 10-20 megatons of TNT, roughly equivalent to the 1980 Mt. St. Helens eruption, or to 1,000 simultaneous Hiroshima explosions.

Four Controversies

The Barringer Crater has provided lively ongoing debate in four areas (Table I). *First*, the origin mechanism has not always been seen as an obvious impact event. As a complicating factor, there are many sink-holes in the Winslow area, some just 30 miles from the crater. Thus underground limestone collapse has been suggested for the crater (Hager, 1953). A volcanic eruption with eventual ground collapse, or else a spontaneous underground steam explosion, have also been popular origin ideas (Gilbert, 1906). Sunset Crater, 40 miles northwest of Barringer, is indeed a volcanic caldera which formed around AD 1060 (Mark, 1987, p. 31). Nearby Indian dwellings in the vicinity were buried by cinders in the eruption (Hoyt, 1987, p. 332). Ash, perhaps from the Sunset eruption, appears in the top six feet of fill within the Barringer crater. There are also hundreds of other small, dormant volcanic vents within 50 miles of Barringer.

Table I. A summary of four major controversies regarding the Arizona Crater.

Topic	Alternative Views
Crater Origin	Volcanism, Erosion, or Impact
Meteorite Size	5,000 tons or 15 million tons
Destiny of Meteorite	Buried or Vaporized
Crater Age	800 years or 200,000 years

Daniel Moreau Barringer (1860-1929), a geologist and mining engineer from Philadelphia, visited the Arizona crater site in 1903 and was quickly convinced of a meteorite impact (Barringer, 1905; see also Foote, 1891). This may well have been the first proposal of impact craters on earth. However, this extraterrestrial origin was not a popular idea a century ago. Even the multiple lunar craters were considered to be volcanic features rather than collision blemishes. The meteorite origin for lunar craters gradually superseded volcanic ideas, especially during the 1940s. Likewise, the impact nature of Barringer Crater is today verified by several factors. Iron-nickel fragments are common in the vicinity; over 30 tons of meteorite material have been collected around the crater, the largest weighing 1,400 pounds. Holdouts against the impact theory have suggested an ancient geologic origin for the depression, with a later, coincidental meteorite fall in the same area (Hager, 1953).

Coesite and stishovite, fused-quartz products of meteorite impact, were discovered at Barringer in the 1960s (Chao, et al., 1960; Hoyt, 1987). Shatter cones, surprisingly, have not yet been reported. These are conical, striated slip surfaces in rocks that are often

Table II. A century of research developments at the Arizona Meteor Crater.

1870s	Crater discovered when "silver" (actually nickel-iron) found nearby.
1891	Geologist A. E. Foote visits the crater and suggests an impact origin. G. K. Gilbert of the U.S. Geological Survey also investigates and proposes a volcanic steam explosion.
1904	D. M. Barringer and B. C. Tilghman form the Standard Iron Company begin sinking shafts in search of the meteorite.
1929	Physicist F. R. Moulton calculates a small size (50 thousand tons instead of 15 million tons) for the meteorite. A disappointed D. M. Barringer dies just three months later.
1953	D. Hager proposes a 200 thousand year age for the crater.
1960	The mineral Coesite is discovered at Barringer Crater.

formed by the sudden, intense pressure of meteorite impact. Table II gives a brief chronology of Barringer Crater studies.

The *second* and *third* controversies, assuming an impact origin, involve the size and present location of the meteorite itself. Daniel Barringer and Benjamin Tilghman estimated a weight between 5-15 million tons for the object. Assuming it was buried in the floor or south wall of the crater, they spent a decade and a half million dollars drilling for it (millions of dollars in today's economy). No sizeable metal object was ever found, even at depths of 1,000 feet. The hopes of Daniel Barringer for a financial bonanza (estimated at \$1 billion) were further dashed when he sought help from physicist F. R. Moulton. Moulton calculated, from collision dynamics, that the meteorite probably weighed only 50,000 tons, 300 times smaller than previously thought (Moulton, 1929). The greatly discouraged Daniel Barringer died the same year. More recently, the object has been estimated at only 12,000 tons, and about 50 feet in diameter (Ley, 1966, p. 246).

Whatever the size, what finally happened to the space rock? Most likely it completely disintegrated, leaving no large nucleus behind. The large meteorite, perhaps traveling at 15 miles/sec, probably melted and then largely vaporized upon impact. The collision is graphically described by LeMaire (1980, p. 125):

A house-size asteroid-80 feet thick, attended by a swarm of lesser meteorites, impacts at 35,000 miles per hour. Unable to escape the projectile, the up-front air compresses to the ignition point: a cylinder of the sky is afire, stabbing the target site below. Just before the alien asteroid touches the resistant Earth, the heat flares outward across the Arizona desert, scaring every living thing for perhaps 100 miles. The irresistible force greets the immovable object; the interface between missile and target converts solid matter into radiation. Knowing only the airless raceway of deep space, the asteroid bores through solid Arizona bedrock for hundreds of feet before its forward portion slows abruptly. The back end continues at 35,000 miles/hour, and it turns inside out. As its face vaporizes, the bulk of the mass liquifies.

The Meteorite's core tunnels 250 feet deep into Arizona bedrock. Sixty thousand tons of metal are converted into gas registering a million degrees Fahrenheit and exerting a pressure of 150 tons per square inch on the confining sandstone and limestone strata. A cloud of gaseous metal shoots 5 miles high; heat and shock waves stab deep underground. Subterranean waters become superheated steam and balloon in all directions: down to the sides, and above. The rock ceiling weighing 300 million tons lifts back like an escape hatch. In an instant the Earth's crust vomits one-third the quantity of all material excavated for the Panama Canal. Vented, the metallic vapors shoot miles into the atmosphere. The mushroom cloud congeals into tiny pellets.

The dust clears. The desert floor ceases its trembling. For evidence of this cosmic encounter, there remains at ground zero a yawning chasm nearly a mile wide and a thousand feet deep that once contained 300,000,000 tons of solid rock.

If correct, this dramatic description explains the absence of any large remaining meteorite core: It was completely vaporized.

The *fourth* and final controversy, of main interest to this paper, concerns the age of the crater. This question may appear to be largely settled, similar to the other debates; a 50,000 year age is much quoted (Figure 3). However, a closer look reveals much uncertainty regarding the crater's history. This confusion is typified by a 1992 college text which gives two different ages for the crater on the very same page: 22,000 and 50,000 years (Payne, et al., 1992, p. 398). Thomas Arny also states that the crater is both 10,000 and 50,000 years old (1994, p. 261, 279).



Figure 3. The postmark used by the store/museum at the Barringer Crater site. Meteor Crater Enterprises, Inc., 603 North Beaver, Suite C, Flagstaff, AZ 86001. The Barringer family still owns the crater property and regards it as a public trust.

Five Age Estimates

Dendrochronology Daniel Barringer took notice of the hundreds of large Juniper or Cedar trees growing around the crater rim. Some revealed as many as 700 growth rings. Since these trees must have begun growing after the explosion, their lifetime becomes a minimum age for the crater (Blackwelder, 1932, p. 559). Today, a century later, the tree ring figure can be

rounded to 800 years, surely the youngest age estimate for the Barringer Crater.

Erosion Benjamin Tilghman reported further evidence for a recent crater formation in 1905. First, he was impressed with the still-sharp edges of ejected boulders (Tilghman, 1905). Chemical weathering is limited by the dry, stable climate, but mechanical weathering is more extensive. Northern Arizona is an area of desert sands and fierce winds, which "quickly" sand blast all exposed rock surfaces. Second, Tilghman noticed a small red sandstone butte one-half mile north of the crater. This butte was hit by a jet of crushed rock debris during the actual collision. Tilghman noticed that the spray of material traveled up the slope and over the top of the butte:

In spite of the evident rapid erosion to which it is subject, [the debris] lies on the surface right up to the cap, without any red sandstone material having fallen or having been washed down upon it. From its appearance it might have been deposited yesterday (pp. 911-912).

More recently, J. D. Buddhue (1961) estimated the crater age from erosion of sandstone. Beneath the north rim there is a protected nine-foot-thick outcrop of Moenkopi sandstone. In less protected areas, Buddhue assumed the protruding sandstone had completely eroded away. Earlier, D. Hager had estimated that the sandstone eroded one foot every 2,500 years (Hager, 1953, p. 851). Thus Buddhue multiplied this rate by nine, arriving at a minimum crater origin age of 22,500 years (Hoyt, 1987, p. 333).

Brown (1933) long ago called for dating caution at Barringer, warning that erosion estimates might lead to a large error. For example, "the talus slopes were built up by the impact and explosion and not by the usual forces that disintegrate cliff faces" (p. 239). Also, deeply eroded limestone and sandstone might not imply long age at all. Instead, heat from the impact could have weakened the rocks and "rendered them prone to rapid corrosion. . . . If such calcining took place, the advanced state of corrosion might have resulted in a matter of months, even with little rainfall (p. 240).

A Geologic Feature Geologist Dorsey Hager concluded in 1953 that the Barringer structure had an ancient geologic origin. He interpreted the crater rim as the remnant of a collapsed dome. Hager proposed that the original complete mound or dome was 1,000 feet (Hager, 1953, p. 821) higher than now, and was formed much longer ago than 5 million years (p. 851). Within the dome, accelerated erosion of strata by solution activity eventually caused collapse of the dome. Hager, after a thorough analysis of data, estimated the crater age at 200,000 years or more (p. 821). This geologic dome idea is no longer popular; there is little doubt of an impact origin. The point here is that the evidence is ambiguous enough to allow such an extreme alternative view of both origin and age of the crater.

Radioactivity At some period after crater formation, a lake existed within its walls. This implies a water table in the area that was about 92 meters (300 feet) higher than present. The water table is now 61 meters (200 feet) beneath the dry crater floor. The earlier period probably coincided with the humid, post-Flood climate that gave rise to the former lakes of the Colorado Plateau (Williams et al., 1992).

Lake sediments within Barringer are about 70 feet thick. These consist of calcareous material, talus accumulation, and small shells. Radiocarbon dates for gastropod shells vary between 16,000-26,000 years (Reger, et al., 1971). However, radiocarbon dates for shells in limestone terrains are very uncertain (DeYoung, 1974). Still, if the lake formed soon after crater formation, then the shell age provides a broad origin estimate.

There are no reports of organic material such as wood being found beneath ejecta, outside the crater. Such a find would provide a valuable opportunity for further C-14 dating of the crater origin.

Wood (1979) reports that meteorite fragments in the Barringer area were dated radiometrically. Some meteorite radioactivity is considered primordial. Other radioactivity is induced in meteorites by cosmic rays while they are in space. Once on the ground they are shielded from cosmic rays by our atmosphere. As radioactivity decreases, the remaining amount is a measure of the sample's time on earth. This analysis showed that the impact occurred "at least 2,700 years ago" (p. 42).

Thermoluminescence In certain solids, small amounts of radioactive impurities give off ionizing radiation. This internal source of energy can remove electrons from their bonding sites, "trapping" them between atoms and resulting in unfilled "holes."

These solids will later emit a low level of light when heated below the incandescent stage. The heating triggers a return of the electrons to their original locations. The process is similar to the light emitted by a semiconductor when electrons move and fill unoccupied holes (a light-emitting diode).

The thermoluminescent technique has been applied to limestone and sandstone from Barringer Crater by Steven Sutton (Hoyt, 1987, p. 333). At the time of collision, the rocks were shock-heated, which "reset the clock" by allowing large-scale electron migration to their original sites. Upon cooling, the internal radiation once again began the process of electron removal. The amount of thermoluminescent light observed today is a measure of the time since collision and cooling. Sutton arrived at a crater age of $49,900 \pm 2,900$ years. However, this result is very tentative for two reasons. First, calibration of the technique is uncertain. Its success, even with pottery, has been limited. Second, the underlying physical mechanism of thermoluminescence is poorly understood. The method is not a simple, straight forward dating technique.

Age Summary Clearly there historically is a wide spectrum of crater age estimates, anywhere between 800-200,000 years or more. And this uncertainty continues to a substantial extent today: Figure 4 shows a century of published age estimates from technical articles and texts. Table III lists the sources shown in Figure 4. Many recently-published crater ages converge around 50,000 years, perhaps an example of "tracking" (DeYoung, 1976). This is the tendency of published data to cluster around a particular value, similar to peer pressure, whether the value is correct or not.

The range of crater ages appears to be a clear example of the inability of science to absolutely date the past. And Barringer is the most studied crater on earth! The lesson is one of caution in chronological studies of earth history.

Table III. A compilation of 31 published age estimates for the Arizona Meteor Crater, in chronological order. These values are graphed in Figure 4.

Author	Year of Publication	Age of Barringer Crater (In thousands of years)
Barringer, D. M.	1905	.7 - 3
Tilghman, B. C.	1905	.7 - 10
Merrill, G. P.	1908	20
Colvocoresses, G. M.	1925	> 100
Boutwell, W. D.	1928	.7 - 5
Jakosky, J. J.	1930	50
Blackwelder, E.	1932	40 - 75
Brown, F. M.	1953	2 - 3
Nininger, H. H.	1952	50
Hager, D.	1953	≥ 200
Beals, C. S.	1958	50
Buddhue, J. D.	1961	≥ 22.5
Hawkins, G. S.	1964	20 - 50
Reger, R. D., et al.	1971	≥ 16.3
McCall, G. J. H.	1973	6
King, E. A.	1976	20-40
Wood, J. A.	1979	≥ 2.7
LeMaire, T. R.	1980	22
Lewis, R. S.	1983	22
Shoemaker, E. M.	1983	20 - 30
Sutton, S. R.	1984	47 - 52.8
Sagan, C., et al.	1985	15 - 40
Burnham, R.	1988	50
Ronan, C. A.	1991	25 - 40
Payne, CA, et al.	1992	22, 50
Kaufmann, W. J.	1993	25
Pasachoff, J. M.	1993	40
Amy, T. T.	1994	10, 50
Engelbrekton, S.	1994	25
Kuhn, K. F.	1994	25

Indian Traditions

Could the Arizona crater formation be much more recent than the popular figure of 50 millennia? If so, is it possible that Southwest Indians actually witnessed the actual impact event? Most authorities agree that Indians arrived in the Southwest relatively recently, within the last 10,000 years.

Several intriguing Indian legends have been published which support the observation idea. They come from the Hopi Indian tribe that still lives in the area today:

The use of the pure white rock flour in Hopi religious ceremonies [finely ground silica from the crater edge] links the crater with a legend current in the tribe. Three of their gods, the Hopi believe, came down from the clouds on to the desert. One made his abode in Meteor Crater. . . . That Meteor Crater should have a place in the legends of the Hopi indicates a fairly recent origin. (Boutwell, 1928, pp. 729-730).

It is possible that the fall of the giant meteorite was observed by the local Indians. Three of their legends concern the crater. According to them, one of their gods came down from the sky, accompanied by thunder and lightning, and buried himself at this spot. Even today, Indians still fol-

lowing tribal customs are not permitted to visit the crater; it is considered taboo. It is also significant that (early) Indians did not participate in the search for meteor iron in the crater vicinity (Heide, 1964, p. 32).

elusive. In the creation view, its formation is postflood and therefore relatively recent. A better understanding of Barringer could be useful in evaluating other collision catastrophes.

Further Study

Odessa Crater After Barringer, the second terrestrial crater was found at Odessa, Texas in 1928. It is a miniature twin of Barringer, 163 meters across (530 feet) and 5.5 meters deep (18 feet). Iron meteorites found at Odessa are very similar in structure and chemical composition to the Barringer site. Could both events possibly have formed from the same meteorite shower (Heide, 1964)? If so, Odessa provides another source for origin data. The Odessa crater is located 540 miles southwest of Barringer. It is generally thought that both meteorites arrived from the north.

The Odessa crater was considered very recent in age until the fossilized remains of a "primitive" horse and an elephant were found buried within it (Mark, 1987, p. 44). The typical age given today is 10,000 years. Investigations of Barringer might well include Odessa. Unfortunately, the Odessa crater nearly has been destroyed by area oil wells, dumping, digging, and bike trails.

Crater Shape The actual shape of the Barringer Crater is almost square, with rounded corners (Figure 5). This shape is little-mentioned in the literature, and is unlike any of the lunar craters. Barringer (1905), Moulton (1929) and other early geologists described the depression as round. Did the lack of early aerial photographs hinder perceptions, or has erosion possibly changed the appearance in just a century? Crater photographs from past decades would make an interesting comparative study. Evidence of rapid erosion, of course, would favor a more recent origin.

If not erosion, how can the unusual shape of Barringer be explained? Shoemaker (1983) refers to pre-existing

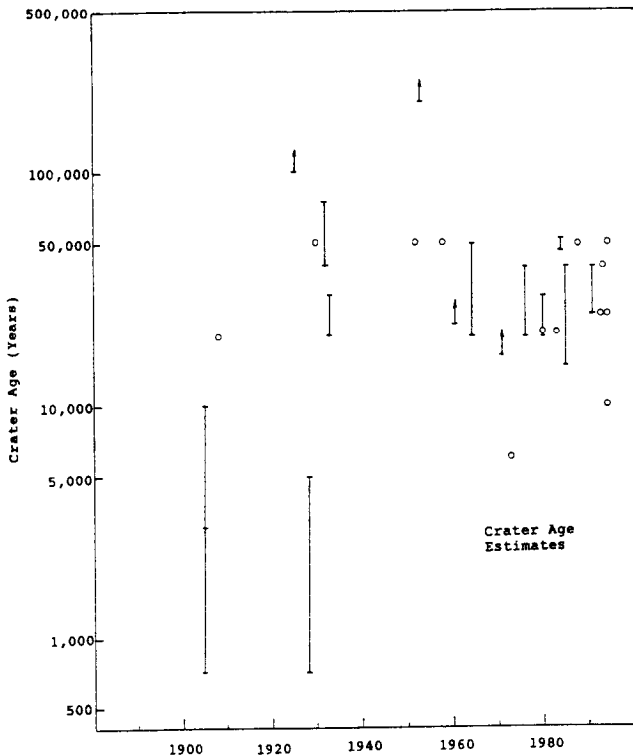


Figure 4. A century of published Barringer Crater ages. The vertical axis is a logarithmic scale which runs from 500 years to 500,000 years. Error bars or arrows are shown where an age range or uncertainty was indicated in the literature. Particular published crater ages are shown by circles. The actual references are compiled in Table III.

It is interesting that the Hopi people speak of a fiery descent from heaven, i.e., a meteorite impact, long before modern geologists recognized this extraterrestrial origin. The Indian observation idea has been discounted by several writers. Perhaps this negative conclusion is based on the presupposition that the crater must greatly predate Indian presence in the region (Blackwelder, 1932, p. 559; Heide, 1964, p. 32; Ley, 1966, p. 244).

Conclusion

Space bombardment of earth is a popular topic today. The failure of slow, uniform changes to explain the appearance of earth has given rise to multiple catastrophism explanations. Collisions are proposed to explain the demise of the dinosaurs, origin of the moon, magnitude of earth spin and tilt, and the mechanism for continental drift.

This paper has reviewed the questions and controversies concerning the earth's best known and most studied collision crater, Barringer. In particular, actual origin date of this instantaneous catastrophe remains

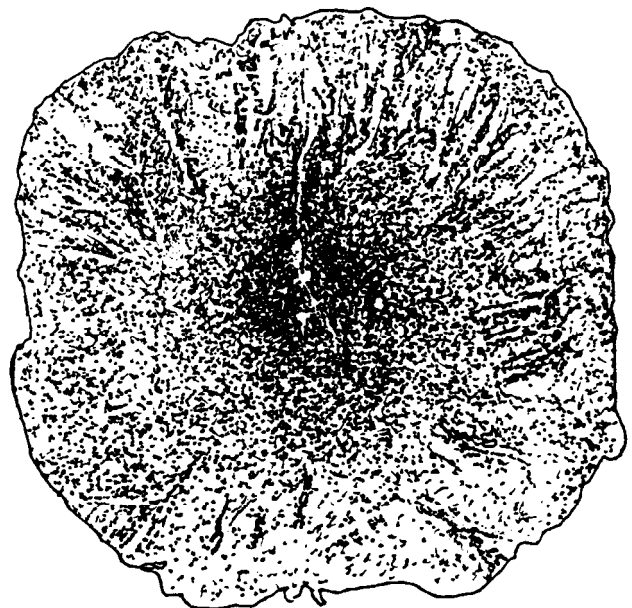


Figure 5. A vertical drawing of the Barringer Crater, with north at the top. Note the square sides with rounded corners. Based on photographs (Beals, 1958, p. 36; King, 1976, p. 99).

fault lines which channeled the explosion in a square pattern. However, LeMaire (1980) rightly compares this idea to channeling a hurricane with tissue paper! The mysterious shape of the Barringer Crater deserves attention.

Other Areas First, Tilghman (1905) reported fresh, unweathered crater debris on a butte one-half mile north of the crater. This particular butte needs to be identified and explored. Second, the slowly-eroding sandstone outcrop below the north rim of Barringer should be remeasured. Is there noticeable change since Hager (1953) studied it forty years ago? Third, personal interviews with area Hopi Indians may clarify their traditions concerning the crater. Such interviews, of course, should be conducted with great sensitivity, preferably with older Hopis in their own language.

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BOOK REVIEW

The Revolution against Evolution by Doug Sharp. 1993. Self published. Available from The Hope Store, 202 Creyts Rd., Lansing, MI 48917. 142 pages. \$5.95.

Reviewed by Don B. DeYoung*

Author Doug Sharp hosts a public access television show in the Lansing area, with the same name as the

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book title. In this book he has summarized creation science in a nontechnical, humorous fashion. There is a helpful discussion of 50 separate evidences for creation. However, many older creation ideas are presented as valid without any updated critique: Paluxy footprints, light speed decay, Riemannian space, moon dust, decaying earth magnetism, etc. This book is for those who want a complete collection of creation literature.