

The origin of large arcs: part 2—impacts can form large arcs

Michael J. Oard

Large arcs are common, yet mysterious, features. A variety of proposed mechanisms leave no definitive explanation. Impacts usually create a deep basin encircled by a large circular or arcuate rim, often formed by thrusts that verge outward from the centre. All the solid bodies in the solar system that have not been resurfaced with lava or debris display this unique signature. Secular scientists have documented about 200 impacts on the earth, but there is evidence of more when proposed impacts, basins, and impact spherules in sedimentary rocks are added. The Chicxulub impact typifies problems with identification, with evidence obscured by subsequent tectonics, volcanism, erosion, and deposition. Use of the moon as an analogy results in overestimating the number of impacts on Earth. A better estimate is found in the high ratio of ‘proposed’ impacts to known impacts. A conservative estimate is 500 continental Earth impacts. Since large impacts would devastate Earth, they likely happened during the Flood, except for a few small impacts afterwards. It is even possible that impacts could have caused the Flood. If so, they could help define the pre-Flood/Flood boundary. This suggests that much, if not all, of the Precambrian sedimentary rocks and some associated igneous and metamorphic rocks are from the very early Flood.

Impacts are a major mechanism for large arcs

Along with other possible mechanisms, large arcuate structures can be formed by meteorite or comet impacts. The rims of impact structures are circular to arcuate, depending upon how much post-impact change has occurred. If the impactor hit at a low angle to the horizon, the crater shape would be elliptical. Where the solid bodies in the solar system are not resurfaced by lava or debris, there are thousands of circular and arcuate rims (figures 1 and 2). Arcs from impacts would have formed by upward and outward thrusting of rock, or an outward vergence.¹ Vergence is the direction the thrust moves.

Impacts did occur on Earth

Considering the number of extraterrestrial impact craters, it is not a stretch to think that the earth experienced numerous impacts. But those features are rare on Earth. According to uniformitarian geologists, there have been 200 impacts on Earth as of 2021, ranging from the Paleoproterozoic, 2.5 to 1.6 Ga, to the Holocene.^{2,3} Of these, about 30 are Precambrian impacts, which are as old as 2.4 Ga,⁴ including the Vredefort impact (figure 3), 250 km in diameter⁵ and dated about 2 Ga, and the Sudbury impact (figure 4), 200 km in diameter⁶ and dated at 1.85 Ga. Since the Vredefort impact is believed to have undergone 9 km of erosion and the Sudbury, 5 km, these structures must be deep crustal remnants.⁷ These Precambrian impacts were significantly larger than the best-known impact on Earth, the Chicxulub impact.

The Chicxulub impact

The Chicxulub impact is centred on the north shore of the Yucatán Peninsula of southern Mexico (figure 5). It is dated ‘very late Cretaceous’, and many scientists believe it was the extinction event for the dinosaurs. It was relatively large and resulted in a multiple-ringed crater with the outer ring believed to be about 180–200 km.^{8,9} The impactor was estimated to be about 10 km in diameter (figure 6) and is considered the best representation of an impact crater on Earth. The Chicxulub impact occurred during the Flood and would have caused ‘impact winter’ for 3–15 years or more and helped to jump start the Ice Age.¹⁰

Clarey is sceptical whether Chicxulub was an impact because it lacks important diagnostic signatures; he thinks the structures could have been volcanic.^{11,12} I agree that the Chicxulub impact is problematic, especially in terms of: its exact size; the lack of an iridium (Ir) anomaly; and relating the impact to a tsunami, the K/Pg boundary, and the extinction of the dinosaurs.¹³ Chicxulub has little iridium and exhibits a small amount of expected melted and broken up rock.

Nevertheless, it has a fairly circular gravity anomaly with a possible peak ring of broken granite and a possible annular low. It also shows up to several hundred metres of suevite, shocked quartz, coesite, a little pseudotachylyte, a small amount of melt, and a few shatter cones (figure 7).¹⁴ Suevite is a broken-up rock deposit that contains deformed melt rock clasts and glass. Coesite is a high-pressure polymorph of quartz. Pseudotachylyte is a special type of broken up rock that contains some frictional melt and is caused by

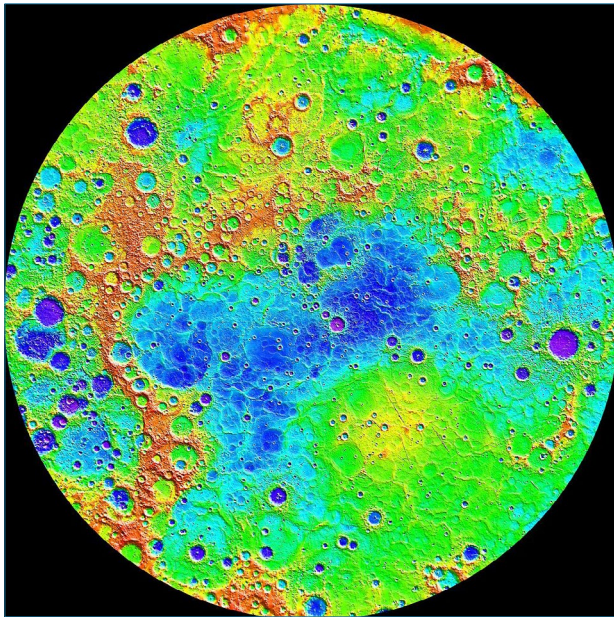


Image: NASA

Figure 1. Colour-enhanced topographic image of Mercury's northern hemisphere from the Messenger spacecraft, showing numerous impact craters



Image: NASA

Figure 2. Jupiter's moon, Callisto, showing numerous impact craters

catastrophic faulting, but it is difficult to distinguish from cataclasis. There were 130 m of suevite encountered in a new drill hole into the claimed peak ring structure.¹⁵ Shatter cones are cone-shaped striated rocks associated with meteorite impacts, but the exact formation mechanism is unknown. Researchers recently found shocked zircon crystals, called 'reidite', associated with the M0077A borehole into the peak

ring structure.^{16,17} Reidite is associated with other impact structures and is considered the only terrestrial mineral diagnostic of an impact.^{18,19}

When all of these impact features are found together in one place, and realizing that shatter cones (see below) are associated with impacts, it seems that the Chicxulub feature represents a true Flood impact. As a detailed analysis of the Chicxulub impact shows, impacts during the Flood do not preserve pristine impact evidence because of tectonics, volcanism, erosion, and deposition. These subsequent Flood features can erode much of the evidence and distort the original impact features.

A rough estimate of the number of 'possible' impact features

There are many impact craters on all the solid bodies in our solar system. They may be obscured by lava flows or debris. The number suggests that the earth has been struck by more than 200 impactors. Using the moon as an analogue, Spencer and I calculated that tens of thousands of impacts, leaving craters greater than 30 km, have struck the earth.^{20,21} But we concluded that there had been far fewer.

It would be valuable to know the true number, since it would tell us more about the Flood and its boundaries. We can set the low end at the 200 recognized impacts, but many 'possible' impacts are probably real. Possible impacts can be identified by their arcuate to circular shape or by their subsurface seismic profile.

The *official* diagnostic criteria are too restrictive. French and Koeberl list four main diagnostic criteria: (1) shatter cones; (2) planar deformation features, such as shock metamorphic features in quartz (figure 8); (3) direct evidence, such as pieces of the impactor, tektites, or spherule layers; and (4) high-pressure/high-temperature minerals.^{22,23} Tektites are millimetre- to centimetre-size spherules composed of black, green, brown, or grey natural glass formed from terrestrial debris ejected during meteorite impacts (figure 9). Most of the time, scientists do not know the location of the impact that caused the tektites, which can sometimes be found over wide areas called 'strewn fields'. These four features have been used for a long time as the only proof of an impact. Morphology is given less weight.

However, these four criteria are ephemeral features that could easily be destroyed or remain undiscovered in both a uniformitarian model and the Flood model. Processes such as tectonism, volcanism, erosion, and deposition could have eradicated evidence. That is probably why there are more possible than confirmed impacts. These criteria alone do not identify all impacts, especially if they are buried:

"Although these criteria have been selected because they are unique physical products of bolide impact, strict adherence to these criteria means that we cannot positively identify buried astroblemes that are

tomographically imaged on three-dimensional seismic data, but are undrilled.”²⁴

Possible candidates were assessed in an article on impacts in Africa. Some will prove to be impacts and some will not. There are 19 confirmed and 40 proposed sites; the latter being more than twice the confirmed sites.²⁵ I suggest that *half* of the possible impacts are true impacts. Thus, there would be about 19 more impact sites in Africa. If we apply this doubling ratio, the total will rise from 200 to about 400.

Huge Archean impacts

There is a surprising and controversial recent discovery of 17 spherule layers in Archean (older than 2.5 Ga) sedimentary rocks in Western Australia and South Africa. The spherules are 0.1–4 mm in diameter and form layers ranging from 0.4–70 cm thick. The layers occur within volcanic, volcanoclastic, and sedimentary rocks many kilometres thick and have been dated at between 3.47 and 2.49 Ga.²⁶ The strongest evidence that they are from impacts is the enrichment of the platinum group, including Ir.²⁷ Koeberl *et al.* were once skeptical that they were from impacts because they are so close together stratigraphically that there would have been too many impacts in a few million years. So, they leaned toward a terrestrial origin. But two of the authors changed their minds.²⁸

Chromium isotopes also indicate an impact origin,²⁹ though some are still skeptical because they cannot find the crater or shocked minerals, although no other explanation is likely.³⁰ Moreover, a crater and shocked minerals could easily be destroyed afterwards—both in secular and biblical history. Recently, shocked high-pressure rutile (TiO₂-II) has since been found within the spherules.²⁶

The scientists claim that the bolides were 10–100 km in diameter!³¹ A 10-km impactor would produce a crater about 150 km in diameter, about the size of Chicxulub. Larger impactors would result in gigantic craters and devastation. Some of the spherule layers are within banded iron formations (BIFs), suggesting a possible connection.

Impact basins

Some cratonic basins look like craters. In addition, they show very thick sedimentary strata, rapid formation as indicated by little deformation during deposition, thinned crust with a raised Moho, and higher density crust.³² Some cratonic basins have been uplifted, deformed, and had their top eroded, such as the Belt Basin in western Montana, northern and central Idaho, eastern Washington, and adjacent Canada. Many cratonic basins are large but are not included in even the ‘possible impacts’ category. But uniformitarian scientists do not know the origin of cratonic basins and why they subsided. It could be that such an origin is too catastrophic for uniformitarians.

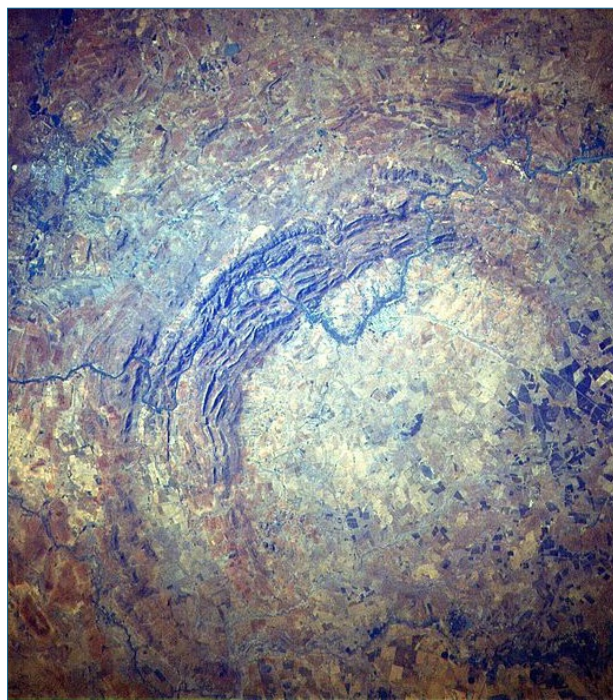


Image: NASA

Figure 3. The upturned central portion of the Vredefort impact structures

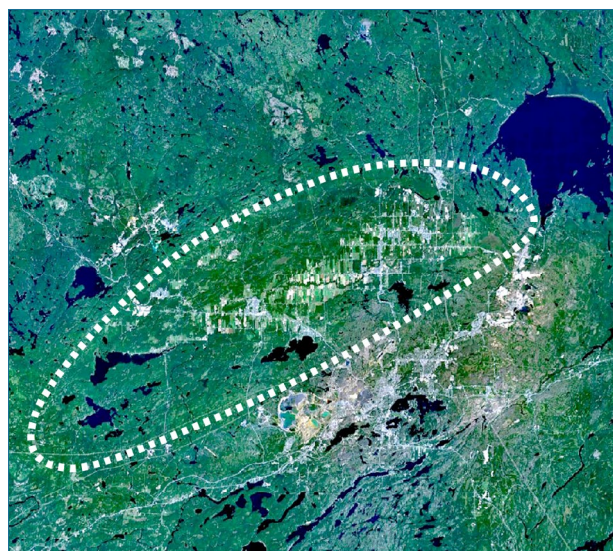


Image: NASA (modified)

Figure 4. The almond-shaped Sudbury impact melt structure, southern Ontario, Canada

A new survey estimates that there are 764 basins.³³ A large proportion of these basins result from non-impact mechanisms, such as strike-slip, foreland, forearc, and fold and thrust basins. There are 66 cratonic basins not included as even possible impact candidates. Most are generally saucer shaped. Some of the non-cratonic basins, such as the 150 passive margin basins, 75 backarc basins, and 130

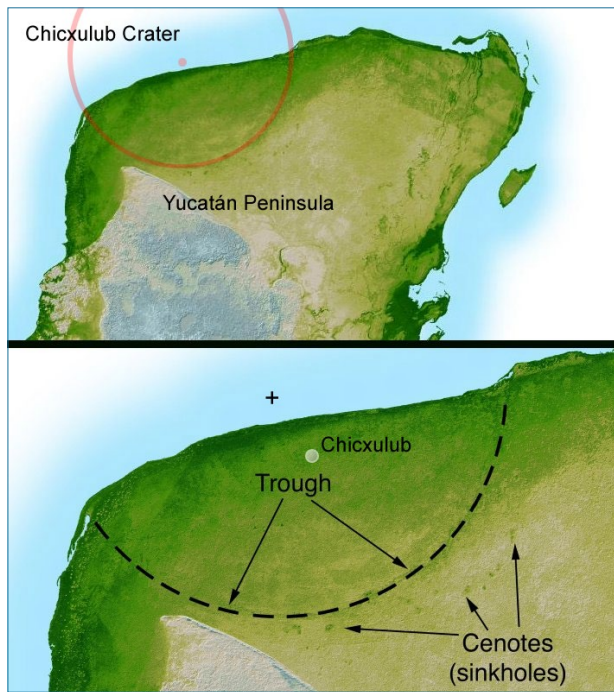


Image: NASA, modified by David Fuchs / Wikipedia Commons

Figure 5. Shaded relief map of Mexico's Yucatán Peninsula showing estimated location and diameter of the Chicxulub impact. Numerous sinkholes cluster around the southern boundary of the impact structure.



Image: Donald E. Davis, Wikipedia Commons / PD (NASA)

Figure 6. Artistic rendition of the Chicxulub impactor striking ancient Earth

rift basins, could be caused by impacts, later distorted by subsequent geological processes, like the elliptical Sudbury structure (figure 4). Many marine backarc basins are caused by extension, but some could have an impact origin, such as the Alboran Sea Basin in the western Mediterranean Sea.^{34,35} Some continental basins are called 'backarc basins', and some may be impact structures, such as the South Caspian Basin and the Western and Eastern Black Sea. If some of these have an impact origin, then it could push the number of continental impacts near 500. If the oceans are included, the number of impacts would have been many more.

The largest known impacts would likely have devastated the earth

Even large 'known' impacts would have devastated large areas, as shown by computer models.³⁶ A 20-km asteroid would produce a crater the size of the Vredefort and Sudbury impacts. Such an impact would emit severe thermal radiation up to 1,000 km away. At 1,800 km, it would cause second degree burns and ignite deciduous foliage. At 2,000 km, it would cause no effect. A 30-km asteroid would produce a crater about 300 km in diameter, about the size of the smallest cratonic basins, and would ignite most life up to 2,000 km away. If the Belt Basin (~500 km) is an impact structure,³⁷ its asteroid would have been 50 km in diameter and would have ignited everything within 2,500 km. Larger impact basins would require a wider area of devastation.

Impacting should be a prominent mechanism for any Flood model. However, some Flood geologists have not addressed them.^{12,38}

Impacts during the Flood

Because of the potential devastation, I place most within the Flood, except for about 30 small ones, such as Meteor Crater, that are likely post-Flood (figure 10). Precambrian impacts likely did not occur during the Creation Week^{38,39} or between the Creation Week and the Flood.⁴⁰ Precambrian impacts suggest a lower Flood boundary in those areas.^{4,41}

The Flood would have destroyed evidence of most impacts, but arcuate features might be remnants. Some secular scientists agree that the arc shape, either on the surface or from seismic profiles, indicates a remnant of an impact crater.⁴²

Often, these arcuate features show thrusting from the centre. Since arcuate mountains along the rim are characteristic of major impact basins on the moon,⁴³ why would they not be so on the earth, too? These rims are often a combination of uplifted and thrust rock,⁴⁴ sometimes overturned by the outward push. Overthrusting would be emphasized by erosion.

Therefore, it is possible that many of the large arc-shaped features on Earth were formed by impacts. The Archean spherule layers would have been caused by very early Flood impacts. However, with rapid sedimentation also taking place, the spherule layers might represent only a few impacts rather than the large number attributed by uniformitarian scientists, who place millions of years between each spherule layer.

Three possible solutions

Why so few impact structures on Earth compared to other solar system bodies? I suggest three possible answers: (1) God protected Earth relative to the rest of the solar system;

(2) the inner solar system bodies were bombarded on Day 4 of Creation Week, while the earth was not; or (3) both. I initially favoured the first possibility.⁴⁵ God oversaw the Flood for His *exact* purpose. The Bible says that God sat “enthroned over the flood” (Psalm 29:10 ESV), started the Flood (Genesis 7), and ended the Flood by the mountains rising and the valleys sinking (Genesis 8; Psalm 104:6–9).^{46,47} So, it makes sense that He would have modulated the number of impacts to accomplish His purposes. In this case, the impacts likely would have come from the solar system passing through a large volume of asteroids and/or comets.⁴⁸ Nonetheless, after studying the surface of Mars, I now believe the third option: both (1) and (2) are true.

The second option is called the ‘Day 4 Cratering Hypothesis’.^{49–51} This proposes that the heavenly bodies were *made* from pre-existing material created on Day 1, and that during and/or soon after assembly on Day 4, small objects were still present which later impacted the planets and moons. The earth was not affected since it was created on Day 1. Faulkner further suggests that the highlands of the moon and all the bodies of the solar system are the result of this Day 4 cratering, while the large basins around 1,000 km in diameter on the near side of the moon that are filled with basalt lava, the maria, were formed during the Flood by a narrow, intense swarm of very large asteroids travelling on parallel paths. Faulkner believes these asteroids only impacted the earth and moon.

The asymmetric distribution of the large craters on the near side of the moon (figure 11) suggests that the bombardment predominantly lasted for just days.⁵² If the impacts took more than a month, large basins, assuming that they occurred during the Flood, would have been more random as the moon rotated.

After initially rejecting the Day 4 Hypothesis,⁵³ Spencer now believes it is true.⁵⁴ I believe the Day 4 Cratering Hypothesis because there was once a strong magnetic field on Mars that resulted in positive and negative remnant anomalies about 10–20 times stronger than on Earth,^{55,56} which line up in an east–west direction (figure 12). They are unlike those on Earth and are about 100 km wide and up to 2,000 km long; they likely do not indicate plate tectonics on Mars, although some researchers have flirted with the idea.^{57,58} They are found mostly in the southern highlands and most of the abundant small-to-medium-sized craters are part of the magnetic anomalies. The magnetic field did *not* remagnetize the large impact basins; large volcanic areas, such as the Tharsis rise; Valles Marineris; and much of the northern lowlands. The large impacts mostly destroyed the remnant magnetization, and the crust was not remagnetized because the magnetic field had already decayed: “Magnetic disruption near large impact craters such as Hellas and Argyre establishes that magnetization came before the impacts”.⁵⁹ The shock of the impacts demagnetized the crust.⁶⁰ The



Figure 7. Shatter cone developed in fine-grained limestone from the Charlevoix crater, Québec, Canada, Collection of the Observatoire de l’Astroblème de Charlevoix

Image: JMGastonguay, Wikipedia Commons / CC BY SA 4.0

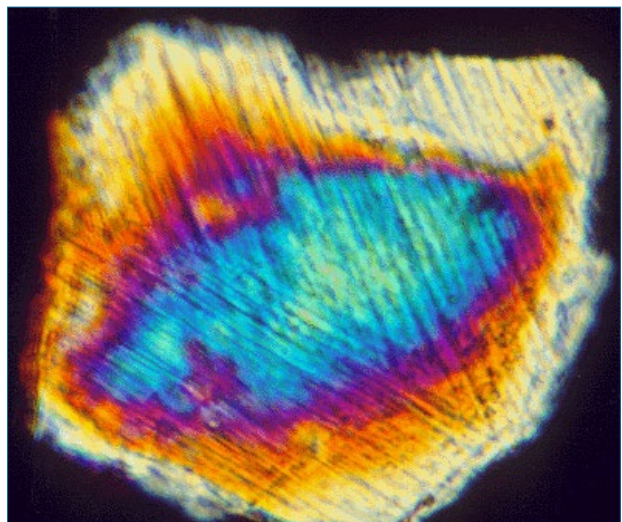


Figure 8. Sand-sized quartz grain (0.13 mm) from the USGS-NASA Langley core showing two well-developed, intersecting sets of shock lamellae produced by the late Eocene Chesapeake Bay bolide impact

Image: Glen A. Izett, Wikipedia Commons / PD



Figure 9. The two common shapes of tektites, dumbbell and teardrop, that resulted from an impact

Image: Brocken Inaglory, Wikipedia Commons / CC BY SA 3.0

Image: Shane Torgerson, Wikipedia Commons / CC BY 3.0



Figure 10. Aerial view of Arizona's Meteor crater

Image: Gregory H. Revera, Wikipedia Commons / CC BY SA 3.0



Figure 11. The near side of the moon

volcanic regions would be expected to thermally demagnetize the area, but the magnetization did not recover later.⁶¹

These observations imply that the bombardment that created the southern highlands was very early in Mars history while the magnetic field was strong. The larger impacts came later when the magnetic field was either weak or had disappeared.

The half-life for the decay of Mars' magnetic field from an electromagnetic current within the core is 308 years.⁶² So, by the time of the Flood—about 1,600 years after creation—Mars' magnetic field would have been very weak. Thus, the large impacts along with some small-to-medium-sized impacts likely can be placed within the Flood. Volcanism on Mars can also be placed during the Flood, suggesting a causal relationship between impacts and volcanism. Faulkner had the Flood impacts affecting only the earth and moon, but they must also have included Mars. It could be that other solar system bodies also received large impacts at this time.

However, Earth does not exhibit similar large impact basins like those on the moon and Mars, which is why I believe that God protected the earth from most of the large impactors while letting a smaller number of the medium to small impactors strike the earth. Some small to medium-sized impacts on Mars were also not magnetized, which would imply that they occurred when the large impactors struck during the Flood. Impact specialist Wayne Spencer once believed this, and probably still does:

“But whether we place impacts in Creation Week or at some other time, it seems inescapable that some unknown factor reduced the effects of impacts on the earth. Some sort of intelligently directed bombardment that limited objects' trajectories could also be a possibility, but this is very close to Faulkner's hypothesis also. It is very difficult to imagine some natural physical effect that would so dramatically reduce the number of impacts on earth. Thus some degree of supernatural protection of earth from impacts seems to be a necessity, regardless of when they took place. If supernatural protection of earth is a possibility, this in turn opens up the possibility of impacts in the solar system at some time prior to the Flood.”⁶³

Image: NASA

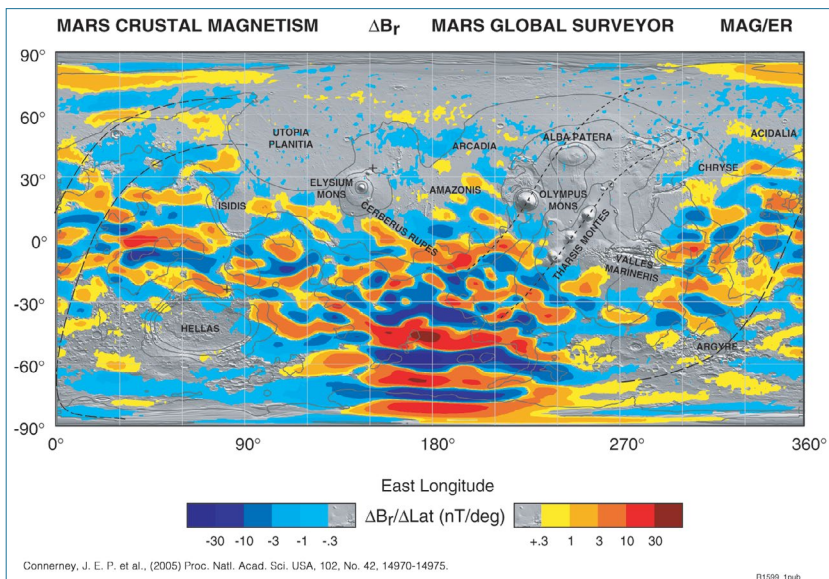


Figure 12. Map of the magnetic field of Mars observed by the Mars Global Surveyor satellite at a 400 km altitude. Red and blue stripes represent magnetic fields with opposite directions. Darker hues represent more intense magnetic fields. To show the location of the magnetic stripes on Mars, the map is superimposed on a topography relief map from the Mars Observer Laser Altimeter instrument.

Impacts could have caused the Flood

Even 500 continental impacts would have supplied a lot of energy during the Flood. It is even possible that they caused the Flood. Many details of an impact origin for the Flood need to be worked out. Some creation scientists suggest that impacts could have initiated Catastrophic Plate Tectonics,²¹ which is also possible.

Impacts help to define the pre-Flood/Flood boundary

If impacts caused the Flood, Archean and early Proterozoic impacts can help define the location of the pre-Flood/Flood boundary, assuming the geological dates are a relative timescale. Based on hundreds of metres of volcanic and sedimentary rocks, and eight,⁶⁴ nine, or more⁶⁵ Archean spherule layers, more than nine impacts could have occurred at this time. Since it is believed the spherules fell from the atmosphere in marine waters, there could have been fewer than nine within biblical Earth history with rapid sedimentation.

Where would such impacts be placed within biblical Earth history? They are unlikely to have occurred during Creation Week, contrary to the beliefs of Dickens and Snelling.³⁹ If they occurred during Creation Week, it had to have been before the creation of vegetation on Day 3. However, celestial objects seem to be the province of Day 4. Moreover, it would be very difficult to place them between the creation and the Flood,⁴⁰ since the spherule layers are found in volcanic and sedimentary rocks over 10 km thick. This implies huge catastrophic action with very large impacts that would likely devastate large parts of the earth.

Therefore, these impacts are better placed in the very early Flood.^{4,66} This deduction is supported by other features of the sedimentary rocks, such as raindrop imprints, black shale, carbonates, and phosphorites, which pass from the Precambrian into the Paleozoic with little or no change.⁶⁷ Raindrop imprints are found even in late Archean rocks. Thus, it is possible that all Precambrian sedimentary rocks, even as old as Archean, are from the Flood. Moreover, since some spherule layers are within BIFs, it can be implied that these enigmatic sedimentary rocks are also from the Flood. BIFs could be a geochemical product of the fountains of the great deep.⁶⁸

Conclusions

Impacts are well known to form large arcs. With 200 impacts confirmed on Earth, more are likely. Based on the large number of proposed impacts, Archean spherule layers, and basins, I estimate the total number at about 500 on the continents. The larger ones were so devastating that they must have impacted during the Flood. There are relatively few

impacts on Earth compared to other solid solar system bodies because practically all these impacts hit all but Earth on Day 4, and God likely modulated the number that impacted Earth during the Flood. The largest impacts bring up the possibility that they may have caused the Flood. This is a hypothesis that needs development. The impacts also indicate that most, if not all, Precambrian sedimentary rocks, and some igneous and metamorphic rocks, formed during the very early Flood.

References

- Melosh, H.J., *Planetary Surface Processes*, Cambridge University Press, Cambridge, UK, p. 236, 2011.
- Schmieder, M. and Kring, D.A., Earth's impact events through geologic time: a list of recommended ages for terrestrial impact structures and deposits, *Astrobiology* 20(1):91–141, 2020.
- Lim, J., Hong, S.-S., Han, M., Yi, S., and Kim, S.W., First finding of impact cratering in the Korean Peninsula, *Gondwana Research* 91:121–128, 2021.
- Oard, M.J., *Precambrian impacts and the Genesis Flood*, *J. Creation* 28(3):99–105, 2014.
- Allen, N.H., Nakajima, M., Wünnemann, K., Helhoski, S., and Trail, D., A revision of the formation of conditions of the Vredefort crater, *J. Geophysical Research: Planets* 127(8), 2022 | doi.org/10.1029/2022JE007186.
- Huber, M.S., Kovaleva, E., and Riller, U., Modeling the geochemical evolution of impact melts in terrestrial impact basins: Vredefort granophyre dikes and Sudbury offset dikes, *Meteoritics & Planetary Science* 55(10):2320–2337, 2020.
- Senft, L.E. and Stewart, S.T., Dynamic fault weakening and the formation of large impact craters, *Earth and Planetary Science Letters* 287:471–482, 2009.
- Gulick, S.P.S., Barton, P.J., Christeson, G.L. *et al.*, Importance of pre-impact crustal structure for the asymmetry of the Chicxulub impact crater, *Nature Geoscience* 1:131–135, 2008.
- Gulick, S.P.S., Christeson, G.L., Barton, P.J., Grieve, F.A.F., Morgan, J.V., and Urrutia-Facugauchi, J., Geophysical characterization of the Chicxulub impact crater, *Reviews of Geophysics* 51:31–52, 2013.
- Oard, M.J., *Flood impacts reinforce volcanic cooling to start the Ice Age*, *J. Creation* 33(3):77–84, 2019.
- Clarey, T.L., Do the data support a large meteorite impact at Chicxulub? *ARJ* 10:71–88, 2017.
- Clarey, T., *Carved in Stone: Geological evidence of the worldwide Flood*, Institute for Creation Research, Dallas, TX, 2020.
- Oard, M.J., *Is the demise of the dinosaurs by a Yucatan impact a myth?* *J. Creation* 18(1):6–8, 2004.
- Christeson, G.L. *et al.*, Extraordinary rocks from the peak ring of the Chicxulub impact crater: P-wave velocity, density, and porosity measurements from IODP/ICDP Expedition 364, *Earth and Planetary Science Letters* 495:1–11, 2018.
- Kring, D.A., Claeys, P., Gulick, S.P.S., Morgan, J.V., Collins, G.S., and IODP-ICDP Expedition 364 Science Party, Chicxulub and the exploration of large peak-ring impact craters through scientific drilling, *GSA Today* 27(10):1–8, 2017 | doi: 10.1130/GSATG352A.1.
- Zhao, J. *et al.*, Shock-deformed zircon from the Chicxulub impact crater and implications for cratering process, *Geology* 49(7):755–760, 2021.
- Cox, M.A., Erickson, T.M., Schmieder, M., Christoffersen, R., Ross, D.K., Cavosie, A.J., Bland, P.A., Kring, D.A., and IODP-ICDP Expedition 364 Scientists, High-resolution microstructural and compositional analysis of shock deformed apatite from the peak ring of the Chicxulub impact crater, *Meteoritics & Planetary Science* 55(8):1715–1733, 2020.
- Cox, M.A., Cavosie, A.J., Bland, P.A., Miljovic, K., and Wingate, M.T.D., Microstructural dynamics of central uplifts: reidite offset by zircon twins at the Woodleigh impact structure, Australia, *Geology* 46(11):983–986, 2018.
- Cavosie, A.J., Timms, N.E., Ferrière, L., and Rochette, P., FRIGN zircon—the only terrestrial mineral diagnostic of high-pressure and high-temperature shock deformation, *Geology* 46(10):891–894, 2018.
- Oard, M.J., *How many impact craters should there be on the earth?* *J. Creation* 23(3):61–69, 2009.
- Spencer, W., *Impacts and Noah's Flood—how many and other issues*, *J. Creation* 27(1):85–89, 2013.

22. French, B.M. and Koeberl, C., The convincing identification of terrestrial meteorite impact structures: what works, what doesn't, and why, *Earth-Science Reviews* 98:123–170, 2010.
23. Zhao, J. *et al.*, Shock-deformed zircon from the Chicxulub impact crater and implications for cratering process, *Geology* 49(7):755–760, 2021.
24. Stewart, S.A., How will we recognize buried impact craters in terrestrial sedimentary basins? *Geology* 31(11):929, 2003.
25. Reimold, W.U. and Koeberl, C., Impact structures in Africa: a review, *J. African Earth Sciences* 93:57–175, 2014.
26. Smith, F.C., Glass, B.P., Simonson, B.M., Smith, J.P., and Krull-Davatzes, A.E., Shock-metamorphosed rutile grains containing the high pressure polymorph TiO₂ -II in four Neoproterozoic spherule layers, *Geology* 44(9):775–778, 2016.
27. Koeberl, C., Reimold, W.U., and Boer, R.H., Geochemistry and mineralogy of Earth Archean spherule beds, Barberton Mountain Land, South Africa: evidence for origin by impact doubtful, *Earth and Planetary Science Letters* 119:441–452, 1993.
28. Simonson, B.M., Koeberl, C., McDonald, I., and Reimold, W.U., Geochemical evidence for an impact origin for a late Archean spherule layer, Transvaal Supergroup, South Africa, *Geology* 28(12):1103–1106, 2000.
29. Kyte, F.T., Shukolyukov, A., Lugmair, G.W., Lowe, D.R., and Byerly, G.R., Earth Archean spherule beds: chromium isotopes confirm origin through multiple impacts of projectiles of carbonaceous chondrite type, *Geology* 31(3):283–286, 2003.
30. Lowe, D.R., Crustal fracturing and chert dike formation triggered by large meteorite impacts, c. 3.260 Ga, Barberton greenstone belt, South Africa, *GSA Bulletin* 125(5/6):894–912, 2013.
31. Johnson, B.C., Collins, G.S., Minton, D.A. *et al.*, Spherule layers, crater scaling laws, and the population of ancient terrestrial impactors, *Icarus* 271:350–359, 2016.
32. Oard, M.J., [Large catatonic basins likely of impact origin](#), *J. Creation* 27(3):118–127, 2013.
33. Evenick, J.C., Glimpses into Earth's history using a revised global sedimentary basin map, *Earth-Science Reviews* 215:1–17, 2021.
34. Oard, M.J., Is the Alboran Basin, Western Mediterranean, an impact crater? part I kinematics, *CRSQ* 55(3):142–154, 2019.
35. Oard, M.J., Is the Alboran Basin, Western Mediterranean, an impact crater? part II dynamics, *CRSQ* 56(1):26–39, 2019.
36. Marcus, R., Melosh, H.J., and Collins, G., Earth Impact Effects Program, <http://impact.ese.ic.ac.uk/ImpactEarth/ImpactEffects/>.
37. Sears, J.W. and Alt, D., Impact origin for the Belt sedimentary basin? *GSA Abstracts with Programs* 21:142, 1989.
38. Snelling, A.A., *Earth's Catastrophic Past: Geology, Creation & the Flood*, Institute for Creation Research, Dallas, TX, 2009.
39. Dickens, H. and Snelling, A.A., *Precambrian geology and the Bible: a harmony*, *J. Creation* 22(1):65–72, 2008.
40. Humphreys, D.R., [Magnetized moon rocks shed light on Precambrian mystery](#), *J. Creation* 28(3):51–60, 2014.
41. Spencer, W., [Magnetized moon rocks, impacts, and the Precambrian—a response to Humphreys](#), *J. Creation* 29(1):116–119, 2015.
42. Stewart, S.A., How will we recognize buried impact craters in terrestrial sedimentary basins? *Geology* 31(11):929–932, 2003.
43. Garrick-Bethell, I. and Zuber, M.T., Elliptical structure of the lunar South-Pole-Aitken basin, *Icarus* 204:399–408, 2009.
44. Price, N.J., *Major Impacts and Plate Tectonics: A model for the Phanerozoic evolution of the earth's lithosphere*, Routledge, New York, pp. 160–163, 2000.
45. Oard, M.J., [Letter to the editor on "How many impact craters should there be on the earth?" Michael Oard replies](#), *J. Creation* 24(1):48–49, 2010.
46. Barrick, W.D., Exegetical analysis of Psalm 104:8 and its possible implications for interpreting the geologic record; in: Whitmore, J.H. (Ed.), *Proceedings of the Eighth International Conference on Creationism*, Creation Science Fellowship, Pittsburgh, PA, pp. 95–102, 2018.
47. Barrick, W., Oard, M.J., and Price, P., Psalm 104:6–9 likely refers to Noah's Flood, *J. Creation* 34(1):102–109, 2020.
48. Spencer, W.R., The origin and history of the solar system; in: Walsh, R.E. (Ed.), *Proceedings of the Third International Conference on Creationism*, technical symposium sessions, Creation Science Fellowship, Pittsburgh, PA, pp. 513–523, 1994.
49. Faulkner, D., [A biblically-based cratering theory](#), *J. Creation* 13(1):100–104, 1999.
50. Faulkner, D., [Letter to the editor, Danny Faulkner replies to "Response to Faulkner's 'biblically-based cratering theory'"](#), *J. Creation* 14(1):47–49, 2000.
51. Faulkner, D.R., Interpreting craters in terms of the Day 4 cratering hypothesis, *ARJ* 7:11–25, 2014.
52. Samec, R.G., [On the origin of lunar maria](#), *J. Creation* 22(3):101–108, 2008.
53. Spencer, W.R., [Letter to the editor, "Response to Faulkner's 'biblically-based cratering theory'"](#), *J. Creation* 14(1):46–47, 2000.
54. Spencer, W., Evaluating the Day four cratering hypothesis, *ARJ* 7:323–329, 2014.
55. Jurdy, D.M. and Stefanick, M., Mars magnetic field: sources and models for a quarter of the southern hemisphere, *Icarus* 203:38–46, 2008.
56. Lillis, R.J., Frey, H.V., Manga, M. *et al.*, An improved crustal magnetic field map of Mars from electron reflectometry: highland volcano magmatic history and the end of the martian dynamo, *Icarus* 194:575–596, 2008.
57. Kerr, R.A., Signs of plate tectonics on an infant Mars, *Science* 284:719–722, 1999.
58. Coles, K.S., Tanaka, K.L., and Christensen, P.R., *The Atlas of Mars: Mapping its geography and geology*, Cambridge University Press, Cambridge, UK, p. 15, 2019.
59. Jurdy and Stefanick, ref. 55, p. 38.
60. Hood, L.L., Richmond, N.C., Pierazzo, E., and Rochette, P., Distribution of crustal magnetic fields on Mars: shock effects of basin-forming impacts, *Geophysical Research Letters* 30(6):1–4, 2003.
61. Lillis, R.J., Frey, H.V., and Manga, M., Rapid decrease in Martian crustal magnetization in the Noachian era; implications for the dynamo and climate of early Mars, *Geophysical Research Letters* 35(L14203):1–6, 2008.
62. Humphreys, R., personal communication, 2020.
63. Spencer, ref. 54, p. 324.
64. Lowe, D.R., Byerly, G.B., and Kyte, F.T., Recently discovered 3.42–3.23 Ga impact layers, Barberton Belt, South Africa: 3.8 Ga detrital zircons, Archean impact history, and tectonic implications, *Geology* 42(9):747–750, 2014.
65. O'Neill, C., Marchi, S., Bottke, W., and Fu, R., The role of impacts on Archean tectonics, *Geology* 48(2):174–178, 2020.
66. Oard, M.J. and Reed, J.K., *How Noah's Flood Shaped Our Earth*, Creation Book Publishers, Powder Springs, GA, 2017.
67. Oard, M.J., [Raindrop imprints and the location of the pre-Flood/Flood boundary](#), *J. Creation* 27(2):7–8, 2013.
68. Oard, M.J., [Could BIFs be caused by the fountains of the great deep?](#) *J. Creation* 11(3):261–262, 1997.

Michael J. Oard has an M.S. in atmospheric science from the University of Washington and is now retired after working as a meteorologist with the US National Weather Service in Montana for 30 years. He is the author of *Frozen in Time, Ancient Ice Ages or Gigantic Submarine Landslides?*, *Flood by Design, Dinosaur Challenges and Mysteries*, and *Exploring Geology with Mr Hibb*. He serves on the board of the Creation Research Society.