What do impacts accomplish in the first hour?

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The next step in developing an impact submodel of the Flood is presented, which is to examine the geological work accomplished by impacts, generally finished in about the first hour. Small impacts are well understood and will be described. Large to very large complex craters are poorly understood, but what astronomers think they know about them will be discussed. Possible modifications after the first hour will briefly be described.

The evidence for even a small number of the numerous impacts that must have blasted the earth is hard to find. I have previously calculated that the minimum number of impact craters on Earth with diameters greater than 30 km should be around 36,000 based on an extrapolation from moon impacts with the earth's stronger gravity.[1] Part of the reason scientists cannot find evidence for all these impacts is likely because the subtle effects left behind are misinterpreted. The problem is that they interpret the data within the paradigms of uniformitarianism, deep time, Earth evolutionary models, and plate tectonics. For instance, a curved mountain range would rarely be considered the possible remains of the raised rim of an impact crater because impacts younger than about 3.5 billion years are thought to be very rare within the uniformitarian paradigm. Early Flood impacts should have been greatly modified, but I would expect some of the mid and late Flood impacts would have more obvious signatures and should be detectable because the late Flood period should have been less violent. One such late Flood impact is the Chesapeake Bay impact crater.[2] But in order for us to find such signs, we need to know the geological consequences of one impact and attempt to extrapolate to numerous impacts.

General features of small impacts

Regardless of the hypotheses for their origin, impact craters are considered the most ubiquitous and significant geological feature in our solar system:

> "Of all the geological processes having—and still—affecting [*sic*] the planets in our solar system, it is only impact cratering that can lay claim to being ubiquitous."[3]

This paper will briefly discuss the geological effects of impacts occurring within the first hour or so and residual geological effects after the final crater is established.

The transient crater

Impacts accomplish their initial work within seconds or minutes. Within seconds a bowl-shaped crater is formed called the transient crater (figure 1).[4] Most of the top volume of the transient crater represents rock or sediment blasted outward as impact ejecta or vapor. The volume lost is called the 'excavation crater'. The lower volume of the cavity is rock or sediment that is displaced or compressed downward and sideways by plastic flow. Part of this compressed rock is melted near the direct asteroid hit. There are several variables that determine the shape of the transient crater, such as the lithology, layering, and rock strength of the target body,[5] as well as the size, composition, velocity, and impact angle from the horizontal of the asteroid. Generally, the transient crater has a depth/diameter ratio of 1/3 or 1/4.[6] In an oceanic impact, some of the ejecta is carried back into the crater by rapid resurge, no matter what the size.[7]

Simple craters

If the impact crater is small, the crater is little modified after impact and generally remains bowl shaped. It is called a simple crater. The rims of such craters are generally circular and usually uplifted (figure 1). They are also commonly either overturned or thrust outward.[8] Sometimes the uplift is significant enough that a circular range of mountains is formed.[9] Figure 2 shows a simple 90-m-diameter crater on Mars. Meteor Crater, Arizona, is a typical example

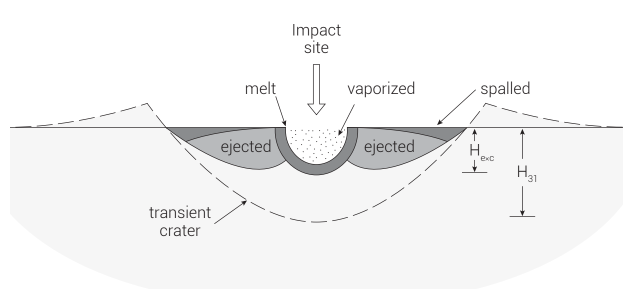

Figure 1. A bowl-shaped transient crater formed within the first few seconds or minutes of impact, showing rock or sediment vaporized, melted, ejected, and displaced (after Melosh, ref. 4, p. 78).

on Earth and is surrounded by uplifted and locally overturned strata (figure 3). Figure 4 shows a piece of the meteorite that formed Meteor Crater.

Small complex craters

These are a little larger than simple craters, the size threshold between simple and complex craters being inversely proportional to the acceleration of gravity for the planet or moon. The threshold diameter for the moon is 15 km. For Mars it is 6 km, and for the earth it is about 3 to 4 km. It also depends slightly on the properties of the planet or moon. Mechanisms that modify a transient complex crater are poorly known.[10]

Several processes are known to transform a transient crater into the final crater. First, the inner side of the rim slumps into the interior of the crater and the rest of the rim slumps down and out (figure 5), with the slump blocks sometimes forming terraces below the rim. Hence the final crater diameter is usually 1.5 to 2 times larger than the transient crater.[11]

Second, the bottom of the transient crater rebounds upward from its original compressed state. Hence the depth of the final crater is much shallower than the transient crater due to both the dynamic uplift of the centre and the slumping of sediment, impact debris, and volcanic material.

The dynamic uplift within the smallest complex craters produces a peak ring in the final crater within about 100 seconds (figure 5), but exactly how this ring forms is still uncertain.[12] Figure 6 shows a small complex crater from Mercury. As the crater diameter becomes larger, the peak ring becomes a central peak complex (figure 7). On the moon, the central peak becomes a central peak complex at diameters greater than 140 km.[13] For large to very large craters, greater than about 300 km, no central peak complex and other unique processes occur (see below).

A bolide impact thins the crust by blasting away the topmost material.[14] Impacts that cause complex craters may also cause the boundary between the crust and the mantle (Moho[15]) to rise upward during rebound.[12] Lunar impact craters commonly possess a positive gravity anomaly in the centre of the

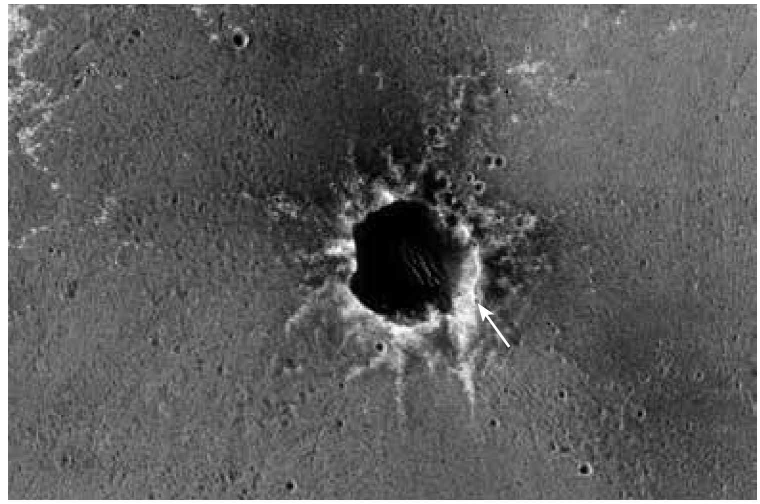

Figure 2. Santa Maria crater on Mars with the rover at edge (arrow). Crater is 90 m in diameter.

Figure 3. Uplifted strata along the edge of Meteor Crater, Arizona.

Figure 4. Pieces of the meteorite that formed Meteor Crater.

basin due to the uplifted denser mantle material and the thin crust.[16] A negative gravity anomaly usually forms an annulus between the central peak or central peak complex and the crater rim because here the crater is filled with lighter sediment, volcanic rock, or breccia.

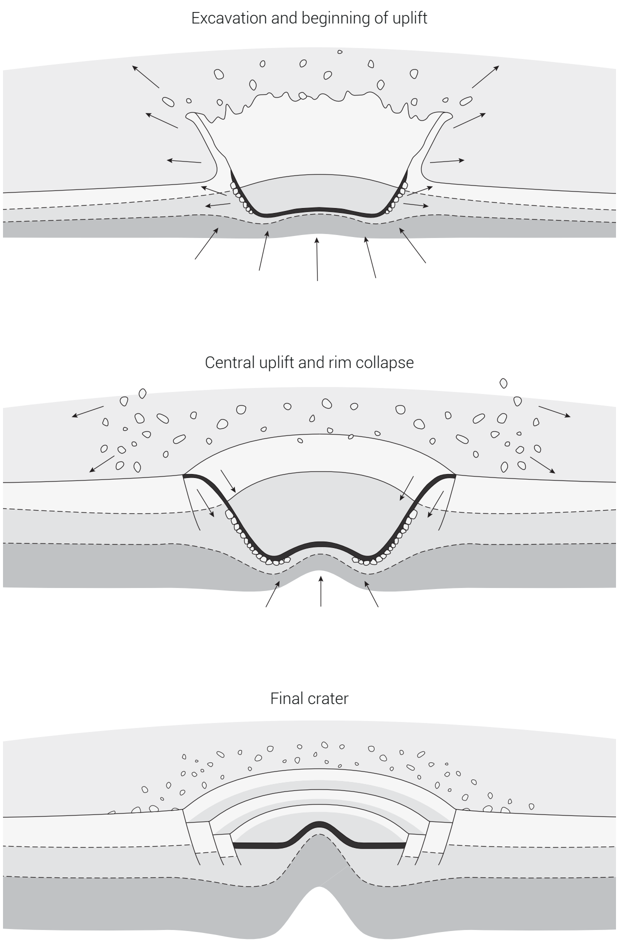

Figure 5. Schematic of the formation of a complex crater with a peak ring (from Melosh, ref. 4, p. 142).

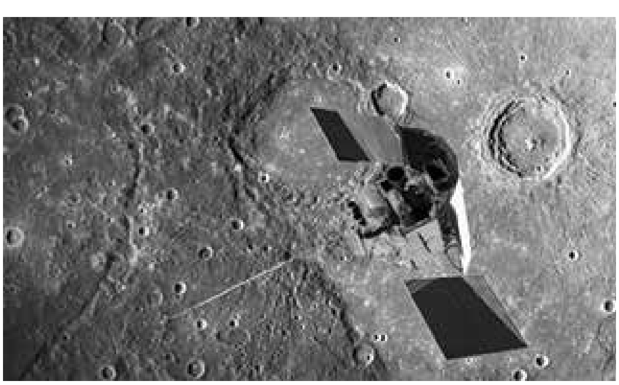

Figure 6. A small complex crater recently seen on Mercury.

On Earth, negative gravity anomalies are predominant within impact craters.[17] This could be due to the relatively small size of these craters or to post-impact modification. Larger impact craters on Earth, although almost destroyed, might however have thinned the crust and raised the Moho. The amount of crustal thinning and the height of the Moho above the average are the main factors that determine the type and size of the gravity anomaly.

During an impact, both the asteroid and some of the target rock melt, but the process and amount of melt production is not well understood.[18] The amount of melt is usually considered proportional to the velocity and size of the asteroid.[19] Small craters produce little impact melt while the larger impact craters may have considerable impact melt. For instance, a 200-km-diameter crater could produce 10^4 km^3 of melt, while a 600-km-diameter crater might produce 10^5 km^3 of melt.[20] The surrounding rocks are also heated.

All these modifications to the transient crater amazingly take very little time. The final crater shape is usually set within about 400 to 800 seconds.[21]

Large to very large impacts

Although there are similarities with small complex craters, large and very large impact craters (those greater than about 300 km on Earth or the moon) seem to have formed differently,[22] apparently because at these larger scales more variables come into play.[23] It is difficult to extrapolate from laboratory test results to the real world. Curvature of the surface of the planet or moon, fracture zones, a variable temperature distribution in the subsurface of the planet or moon, and different strengths of the crust and mantle rocks are potentially influencing factors.[24] Large impact craters of a similar size often differ considerably from each other in other respects. Thus, much remains unknown about the details of large impacts:

> "It may seem incredible that 50 years of study of the impact cratering process have not resulted in a predictive, quantitative model of crater formation. The fact that no such model yet exists, despite many attempts by many authors, indicates that we are still missing major pieces of the puzzle of how rocks respond to sudden shocks."[25]

Very large impact basins observed in the inner solar system include South Pole-Aitken Basin on the moon at 2,500 km in diameter, the Hellas Basin on Mars at 2,300 km in diameter (several on the northern hemisphere of Mars are possibly around 3,000 km or larger, but the evidence is uncertain), and the largest on Mercury, the Caloris Basin, at about 1,500 km. These craters are believed to have been formed by asteroids 100 to 800 km in diameter[26]—assuming they originated from the asteroid belt and were travelling at typical velocities. It is believed that the earth and Venus should have also produced large impact basins.[27]

Planetary-scale properties can be changed

Besides the rearrangement of the surface layer, large impacts may cause planetary-scale changes of the target body, such as changes to the magnetic field, the thermal state, and the rotation, and they may cause volcanism and antipodal effects. Antipodal effects are a result of the impact shock wave passing through the body from the point of impact and impinging on the opposite side. It is even suggested by a few planetary scientists that Mars could have had a planet-wide redistribution of mass during the Late Heavy Bombardment (LHB).[28] Large and very large impacts will also add significant amounts of heat energy to the remaining crust and upper mantle resulting in a higher heat flow from the surface.

Many planetary scientists believe the transient cavity of large complex craters had a similar depth/diameter ratio as those of simple craters.[29] In contrast, the transient cavity from large to very large impacts deforms in complex ways. Instead of the depth and diameter reaching the maximum at the same time as in small craters, it is now thought that the depth and diameter of large and very large impacts do *not* reach a maximum at the same time. In the larger impacts, a maximum volume is eventually reached, and this would be technically defined as the transient cavity. But it is believed that while the diameter of the crater is still increasing, the bottom of the crater, meeting greater resistance from denser rocks, begins to rebound strongly upward. Moreover, the rebound is now thought to overshoot the original ground surface and reach many kilometres higher (figure 7).[26] During the rebound, the rock acts like a *fluid*, but it is unknown how this happens, although there are a number of mechanisms attempting to explain this phenomenon.[30]

Based on the standard ratio of impact depth to diameter, the large and very large impacts on the moon should have blasted well down into the moon's mantle. However, mantle rocks exposed from impacts on the moon's surface are extremely rare.[31] The conundrum of the missing mantle rocks implies that the transient crater depth was much shallower than expected. Basins on Mars between 275 and 1,000 km in diameter are also shallower with less crustal thinning than expected.[32]

The puzzle is especially evident in an analysis of possibly the largest impact basin in the solar system, the South Pole-Aitken Basin on the moon. The diameter is 2,500 km, but there are *no* mantle rocks. None of the mantle was tapped during such a huge impact,[33] and very little basalt flowed into this crater. Many numerical models of basin excavation

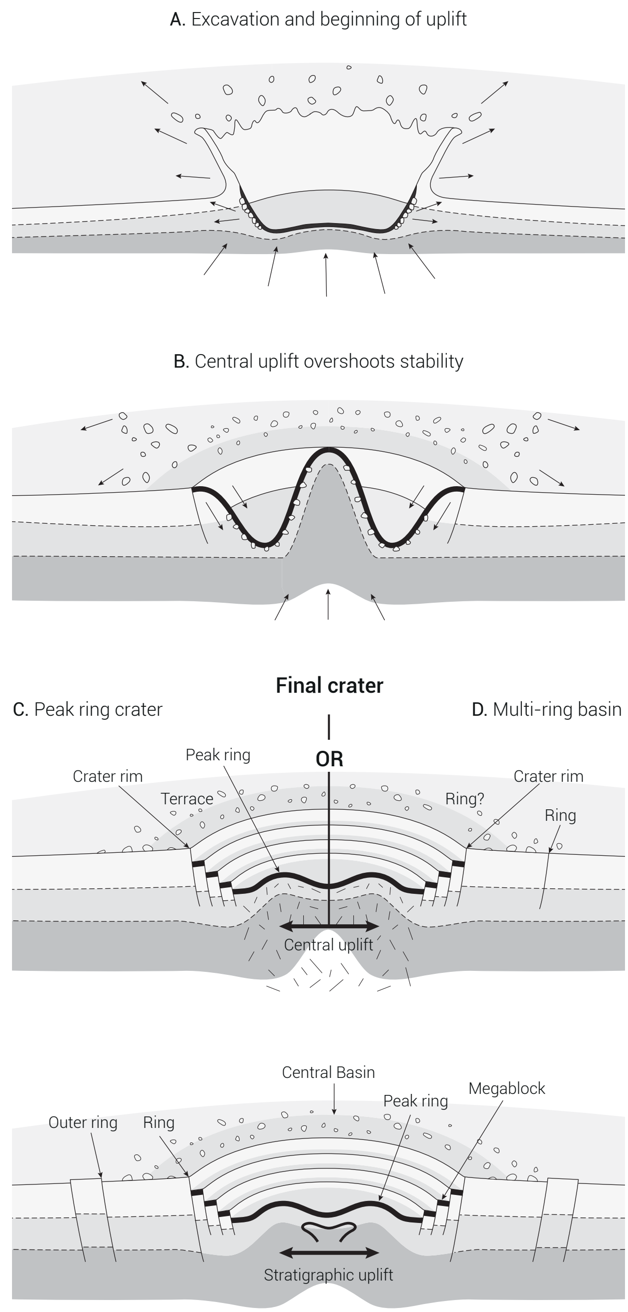

Figure 7. Schematic showing the overshooting central part of the crater resulting in a peak ring complex (from Urrutia-Fucugauchi and Perez-Cruz, ref. 22, p. 1081).

predicted that the impact melt from South Pole-Aitken should have been nearly all melted mantle rock.[34] Why are the mantle rocks missing for South Pole-Aitken, as well as all the other impacts on the moon?[33] It implies that the depth of the transient cavity and also the excavation cavity is much less than smaller crater models suggest. On the other hand, the shallow depth could be caused by the moon being created solid (not cooling from a magma ocean), the thicker crust on the far side of the moon, or the crater caused by a glancing blow.[35]

Late stage modifications

As with smaller craters, large and very large craters are modified in the late stages within about an hour. However, the details of the late stage formation process are still unresolved despite several decades of effort by geologists, geophysicists, experimentalists, and modellers alike.[36]

A few general ideas of late stage modification are probably correct. In the late stage modification, the uplift of the central part of the crater *overshoots* the original ground level by many kilometres (figure 7).[37] Then this central uplift collapses, and as it spreads out from the centre of the crater it can overthrust the material in the annular ring.[38,39] According to planetary scientists, the central part of the crater can then oscillate up and down a few more times, acting more like a fluid, but at lesser amplitude each time. Finally, the oscillatory motion will stop.

At the same time the rim of the crater collapses inwardly. The combination of rim collapse and upward vertical motion near the centre results in a complex intermixture of impact melt and breccia inside the crater. The final crater depth ends up being much shallower than the transient crater depth.

This is also when multiple rings are formed farther out from the rim, but how these outer rings form is unknown. Some of these large to very large craters have several rings and are called multi-ring craters.[40] There can also be an inner ring within the crater rim that formed during crater collapse.

Impacts in water

Impacts in water of course are different from those that strike land. If the impact is small compared to the depth of water, there will be little cratering on the bottom.[41] For asteroids with diameters about the depth of the water or greater, the water will have little or no effect on the cratering process. The rebound of the centre of the crater immediately after impact would mostly be a pulse of water shooting high into the air.

The most significant effect of impacts striking water is that a fair amount of water will be blasted up into the air[42] and large tsunamis will result. In the excavation of an oceanic crater, a thin layer of water is ejected from the rim almost straight up, which soon collapses and plunges onto the water surface (figure 8). So impacts cause water to shoot high into the atmosphere at both the rim and the centre of the impact. Could this be what is described in the Bible as

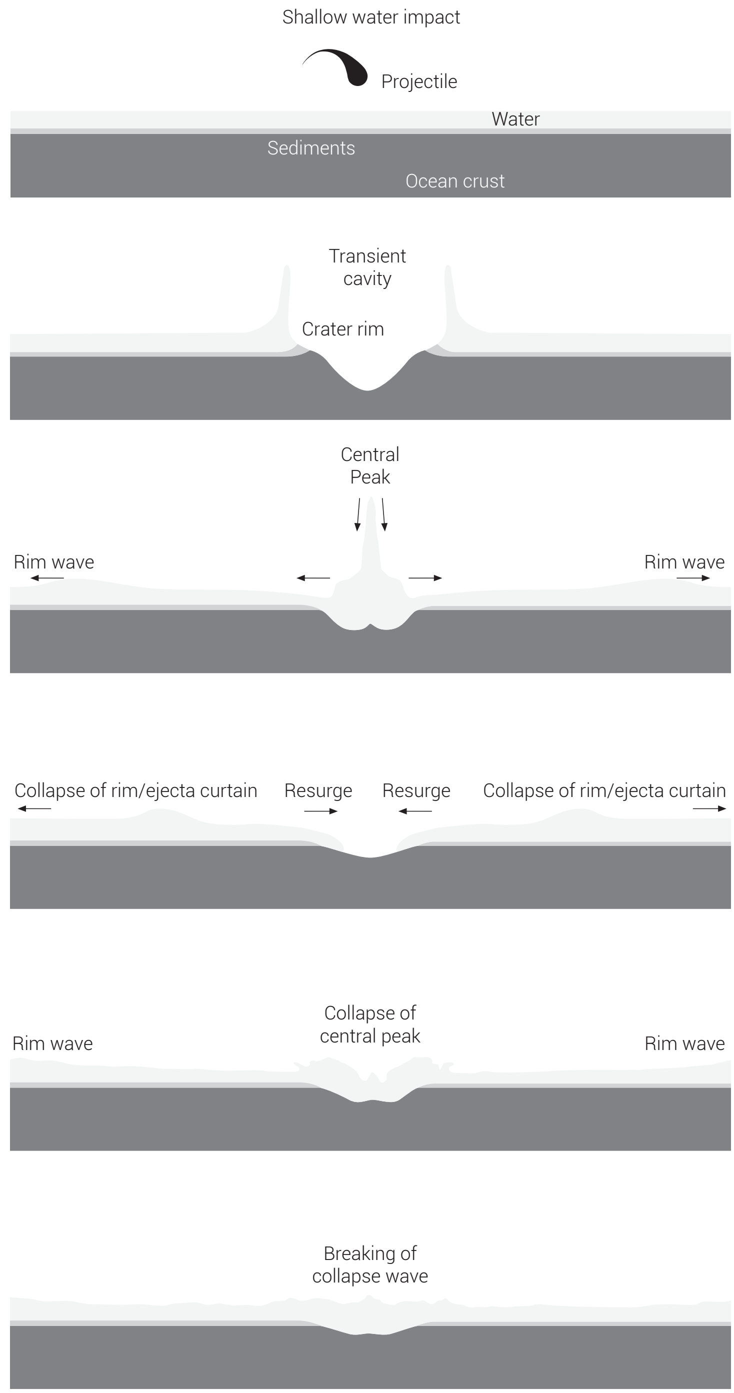

Figure 8. An impact in shallow water, shooting water upward along rim and in the centre (from Wünnemann *et al.*, ref. 41, p. 1895).

"on the same day all the fountains of the great deep burst open" (Genesis 7:11b)?

Much water is also vaporized during transport to the upper atmosphere:

> "Another important difference between continental and oceanic impacts is the vaporization of water expanding as a vapor cloud in the upper atmosphere. Earth's climate and atmospheric circulation may be severely perturbed by the injection of a large amount of vapor … ."[43]

The above statement was made assuming one impact. However, with multiple impacts occurring simultaneously during the very early Flood, a huge amount of water vapor, and probably also liquid water, would be injected into the atmosphere and above.[44] The liquid and vapor would be spread all around the earth by the upper winds and general circulation of the earth, whatever that was before the Flood, and fall as torrential worldwide rain early in the Flood. Such a rainfall would tend to slow up as the number of impacts decreased early in the Flood. But, it would still take many days before all the water fell out of the atmosphere by gravity. Such an impact mechanism can easily explain the 40 days and night of heavy rain over the earth.

Impacts in water cause tsunamis. The size of the tsunami wave is related to the projectile diameter, but it will be different than a tsunami resulting from a large earthquake. Tsunamis would move at hundreds of m/sec away from the impact, and as they move through deep water they are large swells that may not even be detected on board a ship. It is only in shallow water that a tsunami builds up to a giant wave.

Impacts cause two groups of tsunamis: one from the pushing outward of water at the rim and the other from the collapse of the central uplift, which will follow the rim wave (figure 8). Impact tsunamis decay much faster than earthquake-induced waves. There are two reasons for this weaker tsunami for the same amount of energy. First, a resurge flow returning water back into the crater would diminish the strength of the tsunami waves and also help fill up the crater with debris.[45] Second, since impact tsunamis are much larger, the breaking of the wave in shallow water starts on the *edge* of the continental shelf and not near the beach.[46] Breaking so far from shore dissipates much of its energy, and the roll up on land would be much less than expected.

The largest impacts occurred quickly

There is evidence that the largest impacts occurred quickly, as even some uniformitarian scientists reluctantly admit during the LHB:

> "On the other hand, there are fewer large lunar basins on the farside. It is unlikely that large impacts concentrated on one side of the Moon and smaller impacts on the other side, or that a thinner crust on the nearside resulted in larger basins than on the farside, because crater diameter depends mostly on impacting energy and momentum, not on the properties of the target."[47]

Solar system scientists are thinking of random impacts over millions of years and so reject the implications of the non-random distribution of large impacts on the moon which would suggest that the largest impacts hit the near side before the moon barely rotated one quarter of its axis. So they attempt to come up with an alternative hypothesis. But, regardless, the straightforward interpretation of the observations indicates that the very large impacts struck the moon quickly before it could rotate much.[48]

The largest craters are not circular

Practically all impact basins in the solar system are circular. This used to be the main argument for a volcanic origin of these craters. It seemed like a reasonable argument at the time, but nature is complex. It was discovered that an elliptical crater would form only when the impact angle compared to the horizontal was quite low, probably at an impact angle of around just 5 to 15°.

However, most large impacts are not circular but slightly-to-moderately elliptical. Although elliptical large craters can occur with low-impact angles, it is more probable that the ellipticity of the largest craters is due to the curvature of the planet.[49] For instance, the new Messenger flyby discovered that the largest impact basin on Mercury, the Caloris basin, is larger and more elliptical than previously thought.[50]

Crater asymmetry can also be caused by the properties of the target.[45] Since the effects of an impact are related to the vertical component of the impact angle, more oblique impacts would be less energetic.[51] So, in looking for the signs of early Flood impacts, we should not necessarily look for a circular or arc-shaped feature for large impacts, although such features would be suggestive of an impact origin, remembering that there are other geological causes of such features.

Volcanism

There is little doubt that large and very large impacts cause volcanism.[52] Magma is caused by the heat of impact and decompression of the subsurface rock by blasting away the surface rock, which causes isostatic uplift of the bottom.[53] Volcanism is quite common in the solar system, some of it is associated with impacts. The large craters on the near side of the moon have mostly been filled with basalt. Other large and very large impact basins are commonly filled with volcanic material, such as Utopia on Mars. But there is still a lot of controversy on the volume of magma produced.

Antipodal effects

The shock wave that is generated by such planetary-scale impacts decays with distance, but the decay curve is strongly affected by the planet's shape and layering.[54] The wave is generally damped proportional to distance from the impact, but the phenomenon is complex. At the opposite side of the planet or moon, antipodal effects can occur. One antipodal effect is spallation, which is the fracturing, fragmentation, or upward heaving of rock caused by a shock wave striking the surface.[55] But the exact antipodal effects depend upon a number of variables, such as the planet shape, the layering, and the properties of the core, which include such properties as its radius, density, and whether it is liquid or solid.[56] Antipodal effects of large and very large impacts are uncertain.

Mascons—positive gravity anomalies in impact basins

Sometimes, during the upward overshooting processes of the centre of the crater during the modification stage, the rock does not fall as far back as it should. It is as if some process has caused inelastic flow or 'freezing' of the solid rock. Thus, after modification, the central area of the crater becomes super-isostatic. A large positive free-air gravity anomaly becomes locked in, probably because of an uplifted Moho and upper mantle that is locked into place. These are called mascons.[57] A ring of negative gravity anomalies usually surrounds the positive gravity anomaly located in the centre. Mascons were originally discovered on the near side of the moon and the number has increased with further exploration. Some mascons have also been discovered on the far side of the moon.

It was once thought that super-isostatic mascons were caused by denser basalt filling these basins after the impact basin was formed. However, it has since been shown that mascons formed early in the impacting history and are rarely caused by the basalt fill, although the basalt would add a little to the positive gravity anomaly.[58] Therefore mascons were formed during the cratering process.

Mascons can relax with time toward isostatic equilibrium,[59] but the relaxation time seems to be variable. Some mascons have not relaxed at all, which presents a minor anomaly to uniformitarian solar system science in that some of these basins with mascons are considered very old, formed during the LHB: "The remaining enigma, then, is why Newton, Copernicus, and Ladon have retained such large amplitudes of Moho relief, as they do not appear to be the youngest."[60] One would have thought the mascons would have relaxed by now, *if* they are that old.

Mascons were once believed to have formed on Mars, but with time most of them have since relaxed by subsidence.[61] Why would the moon have so many mascons? No mascon has been detected on Earth that is associated with known impacts, but they could have existed for a while after the impact.

Sometimes, the collapse of the dynamic central uplift was so efficient that the impact basin ended up with a negative gravity anomaly. Could such a geophysical feature be caused in the same way as a mascon, but during the downward fall of the central uplift, 'freezing' the rock lower than expected as an 'anti-mascon' with a negative gravity anomaly?

Whether a crater is a mascon with a positive gravity anomaly in the centre or whether the whole crater is one big negative gravity anomaly depends on several variables.[52] The relaxation of the gravitational forces after the modification stage, whether causing basin collapse or subsidence, would likely be a long-term effect well after the impact process. But the general long-term tendency would be for isostatic rebound because of the lost crust. So, a large to very large impact crater may continue to cause vertical tectonics either up or down well after the impact. However, these residual effects are controversial:

> "Alternatively, the lithosphere may rebound isostatically over approximately the next 10^4 yr, on a time scale similar to that predicted for post-glacial rebound on Earth … ."[62]

This timescale assumes one isolated impact, but with thousands of impacts close together, many more fractures, the heating of the crust and upper mantle, and the lowering of the upper mantle and crustal viscosity, differential vertical tectonics is expected to be much faster than on a 10,000-year scale. They could easily start soon after the modification stage of the impact and be a source of vertical tectonics later in the Flood.

The excavation cavity

The material excavated from the crater is much less than the volume of the transient crater for complex craters. The excavation cavity is defined as the material that is blasted out of the crater as the impact ejecta, and this material generally forms a ring outside the crater immediately after impact. The maximum depth of the excavation cavity is considered to be about one third the transient crater depth (figure 1).[63] It was thought that the volume of material excavated was about one half the volume of the transient crater, but more recent estimates of the excavation cavity for several of the very large craters on the moon indicated that the excavation cavity was smaller than expected.[57] This is especially so when considering that large and very large impacts are not very deep (see above).

Phase changes

A solid phase change is defined as the process where one mineral configuration is changed to another, caused by changes in pressure or temperature. For instance, basalt or gabbro transform to eclogite under higher pressure. Such a phase change results in a mineral with a different volume and density. Eclogite is generally about 15% denser with a volume 15% less than basalt.[64] Impacts have enough energy to cause phase changes, such as transforming gabbro or basalt into denser eclogite,[65] but it is not known how significant this effect is. A phase change upon impact could potentially cause a denser phase and a deeper crater, but upon uplift to a lower pressure the phase change can reverse. Phase changes are ignored in numerical impact models,[66] and so the effect of phase changes during impacts is not well known.

Discussion

Uniformitarian astronomers think of an impact in isolation, separated from other impacts by tens of thousands to millions of years. The effect of one impact then has time to settle down, and so astronomers think only in terms of the geological effects of one impact, small or large. But if over 36,000 impacts occurred during the one-year Flood and mostly at the beginning, the bombardment would be much more complicated. There would be additional geophysical and geological effects, such as some areas of Earth becoming saturated from multiple, simultaneous impacts; interference from tsunami waves and atmospheric winds from different asteroids; large areas of the earth losing variable amounts of its crust; massive volcanism; etc. The concept of so many impacts striking quickly is a major challenge to understand within a Flood model. Nevertheless I am compelled to try, and any mistakes I make can be corrected by other creationists.

The idea of more than 36,000 craters greater than 30 km in diameter, all occurring within one year, is a shocking idea to many creationists. But I believe the deduction is sound, based on what we observe on other solid solar system bodies, especially on the moon. I might add that over the years a number of creationists have proposed that impacts initiated the Flood or at least triggered catastrophic plate tectonics (CPT), which caused the Flood. Carl Froede Jr has conveniently referenced those creationist papers.[67]

There certainly was enough energy to cause a Flood, produce the sediments, create basins, cause vertical tectonics, etc. Tens of thousands of impacts would help level high pre-Flood terrain by blasting mountains to pieces, but other mountains would form as a result of the central uplift and the uplifted rim. The debris would tend to fill up low terrain, contributing to the leveling of the earth. For a planet with so much water, such a leveling would have the net effect of flooding the entire earth. This could be the reason why the floodwater covered all the land by Day 150.

With so many impacts acting in concert, the earth would be tremendously out of isostatic balance by Day 150 but the amount of imbalance would vary across the earth. Thus, the restoring of isostatic equilibrium could be one of the mechanisms causing differential vertical tectonics late in the Flood to drain the floodwater during the Retreating Stage.

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