Geophysical Effects of Impacts during the Genesis Flood

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ABSTRACT

There is clear evidence that impacts have occurred on Earth. To evaluate the possibility of a large number of impacts occurring during the Flood, it is important to consider their geophysical effects. The major effects include powerful shock waves that could trigger mineralogical crystal structure changes in the 400-660 Km depth region in the mantle. This could trigger subduction of the preflood ocean floor as suggested by Dr. John Baumgardner. A large number of impacts would also vaporize great quantities of water, some of which would condense as rain. Huge quantities of dust would be ejected by the impacts into the stratosphere. This would lead to low light levels for approximately 3 to 6 months and cold temperatures at the surface for a few months after this. Many other local and regional catastrophic effects would be produced by the impacts, including large tsunami waves, unusual winds, and possibly acid rain. It is concluded that though impacts would make the Flood more violent and more uncomfortable for Noah and his family, it would be a survivable event and is not in conflict with the chronology of the Flood as given in Genesis.

INTRODUCTION

Recent research on Earth impact structures has made great strides in identifying Earth impacts, even though erosion and other processes may have severely altered the original craters. This research has been motivated primarily by the Alvarez extinction hypothesis. Young age creationists are generally quite satisfied with Noah's Flood and its aftermath as an explanation of the Earth's dinosaurs. However, creationist geologists and geophysicists are making significant progress in developing scientific models of various details of the Genesis Flood. Creationists have suggested that impacts have occurred during Noah's Flood and may have even triggered the Flood in some way. (See DeYoung and Froede [7,pp 23, 30], Aldaney [1, pp 11-12, 2, pp 133-136], and Parks [18, pp 144-146] and Snelling [19, p 38].) The companion paper, "Catastrophic Impact Bombardment Surrounding the Genesis Flood" [21] argues for a catastrophic bombardment event during Noah's Flood, with impacts dropping off in frequency thereafter. There is a need to look carefully at impact physics in order to determine what is feasible and plausible in terms of the effects of impacts. Assuming there was an impact bombardment event during the Noahic Flood, could the effects of such an event be consistent with the Genesis account regarding the timetable of events? If a bombardment did occur, how many objects underwent collisions with Earth?

This paper will offer some very preliminary estimates. Suggesting such a bombardment event is consistent with a young-age catastrophic approach to geology and should help creationists explain some of Earths features in a young-Earth time frame. Andrew Snelling has commented to this effect:

> The discovery and investigation of extraterrestrial impact craters on the earth is potentially opening up a whole new panorama of feasible mechanisms and processes that would satisfactorily explain how the catastrophic geological developments and the time-frame portrayed by the biblical account of Noah's Flood could have given us the geological features that we see on the earth today [19].

Thus, acknowledging impacts on Earth should be viewed as a positive development in creationist science. But, it is important to allow Scripture to set the constraints on what is possible and physics to set the constraints on what is plausible. In this paper, emphasis will be placed on what is clear from Scripture and from impact physics research to evaluate the consequences of an impact bombardment event surrounding Noah's Flood. It is possible that in the future, further research from creationists, either from Biblical considerations or from geological considerations, could rule out what will be suggested here. But this paper will show that an impact bombardment during the Flood could be a survivable event for Noah and his family, and that such an event would be consistent with the Flood chronology.

Impacts on Earth

Major impacts are observed to be rare events. Yet, the number of impact craters on the inner planets and our Moon is large, compared to Earth. This leads to a question creationists must answer: what happened to all of Earth's impacts? Even though the number of impacts is much less on Earth than on other solar system objects, Earth's distribution of crater sizes tends to be similar to that of the Moon and Mars [10]. This implies that Earth was very likely struck by the same population of objects that produced the craters on other objects in the inner solar system. When did these impacts occur in Earth history? In the evolutionary view, they are viewed as a natural outcome of the formation of the solar system. In the evolutionary history of the solar system, a period known as the late-heavy bombardment ended sometime after 3 billion years ago.

Creationists have few options in relating impacts to Earth history in a young age perspective. One option for creationists could be to suggest an episode like the proposed late-heavy bombardment during the creation week. However this is not acceptable in my opinion since it would create theological problems similar to those of the Gap Theory interpretation of Genesis. Also, such an event would be much more intense than the bombardment I would propose during the Flood. No life could survive on Earth under something like what has been proposed for the late-heavy bombardment. It is possible some impacts could have occurred between creation and the Flood, but they would not be many over so short a period. However, impacts could naturally fit into Earth history as something which accompanied God's judgement during the Flood [17]. The small number of impacts found on Earth could be a logical result of the Flood's sedimentary and tectonic processes destroying many of the craters. Impacts could also have occurred after the Flood, producing craters in sediments (and nonsedimentary rocks) that were formed during the Flood.

If a solar system catastrophe of some kind caused a bombardment to begin immediately before the Flood began and the impacts continued for some time after the Flood, evidence would be found on Earth throughout the geologic column. This is the case. The number of known Earth impact sites is likely to be over 120 [8, and 21]. The largest numbers of astroblemes are found in Paleozoic strata, but crater remnants have been found throughout the entire phanerozoic [21, 9]. A few impact sites are known in Precambrian rock [9]. There are also locations where small spherules which seem to have the composition of meteorites are found in Precambrian strata [13]. The primary indicator of impact, other than actual meteorites, is in shock metamorphic minerals such as coesite and stishovite found in crater structures. Impact produces shock patterns in these minerals that cannot be explained by any kind of volcanism [8, also 3]. The number of observed craters on our Moon is probably the best indicator of the number of impacts which actually occurred on Earth.

The total number of all sizes of meteoritic bodies and the total number of large impacts capable of producing global effects are yet to be determined from a creation point of view. Though craters on the Moon have been studied a great deal, estimates of the total number of impacts on the Moon vary. The variety in this number is due to the various applications of statistics to Lunar cratering and how age estimates have been correlated with lunar surface geology. The best approach at the moment would seem to be to base an estimate on the total number of known observed craters on the Moon. Following is a quote of Stuart Ross Taylor [23, p 173] on the number of Lunar impacts of various sizes:

> What was the source of the bodies responsible for the production of 40 lunar basins over 300 km in diameter, 1000 craters between 30 and 300 km in diameter, and over 10,000 craters, the smallest of which would resemble Canon Diablo or Wolf Creek?

Note that an object producing a crater 300 Km diameter on the Moon would produce a crater on the order of 60-70 Km diameter on the Earth. It is believed by some planetary scientists today that Earth once had 300 impacts of this size and larger [22]. This could be an overestimate since it assumes the number of a given size on the Earth to be 20 times that for the Moon. This is based on the fact that the Earths surface area is roughly 16 times that of the Moon and Earth's gravity is about 6 times greater than the Moon. It seems logical that these factors would apply but observational evidence does not support such a large difference in the meteoritic dust influx rate. The same could apply to larger objects. It is not clear at all how to transfer meteoritic influx figures for the Moon to the Earth. For meteoritic dust, the amount of dust accumulating on the Earth per year is probably about the same up to double that for the Moon at most [20, pp 15, 26, and 29]. This would imply perhaps 40 to 100 impacts producing craters on Earth of at least 60 Km diameter. The number of smaller impacts would be in the thousands. I suspect 10 to 20 thousand would be a reasonable estimate, but this is very tentative. It is not well known what the minimum size of an impactor would be which would have global climatic consequences. It would probably be an object between 1 and 5 Km diameter. A 1 Km diameter object would produce a crater on Earth roughly 16 Km in diameter, depending on its velocity. A 60 Km diameter crater would correspond to a projectile diameter between 1 and 5 Km. The Acraman structure in Australia is believed to have been produced by an object close to 5 Km diameter and its main rim diameter (prior to erosion and alteration but after slumping) was approximately 87 Km in diameter [26, p 209].

History of Impact Physics

Most of the important research on impact physics followed World War II and was motivated mostly by the desire to defend military installations against heavy explosives. The space program provided some impetus for the study of meteorites and collisions due to the concern for the safety of astronauts in spacecraft. Impact cratering mechanics has developed into a science that is quantitative but not highly precise. Projectile experiments can simulate low energy collisions and small scale craters, whereas nuclear weapons tests have provided some insights into explosion cratering on larger scales. The atmospheric effects of volcanic ash eruptions, which have been observed, are similar in certain ways to the atmospheric effects of impacts. But none of these phenomena provide perfect analogies to large impacts. Fairly involved scaling laws and mathematical approaches have been used to be able to apply experimental cratering mechanics studies at one energy scale to problems at higher energies beyond what can be experimentally studied. Many aspects of dynamics, thermodynamics, rock mechanics, and geochemistry enter into understanding cratering phenomena.

This paper will address the large scale global effects that are possible from large impacts and relate it to a current creationist understanding of the Flood. A crater such as Meteor Crater in Arizona is too small to be of interest in this discussion. Indeed, compared to the very large impact structures found in the solar system, even the largest sites on Earth are small. What is the reason for this? Could impacts have triggered processes of the Flood? What would be the effects of impacts into the ocean? What would be the climatic effects of the great amounts of dust that would be lofted into the stratosphere by large eruptions? These are some of the questions to be addressed.

Several proposals will come from considerations of impact physics. First, the shock pressure wave for large impacts would be capable of inducing a mineralogical solid state phase change even at a depth of 400 to 600 Km. This could serve to trigger the subduction mechanism outlined by Dr. John Baumgardner [5]. Thus, a significant number of impacts could influence catastrophic plate tectonic (or other tectonic) models. But impacts cannot produce lateral motion of continents and cannot be a cause for all aspects of a world-wide Flood. Second, impacts into the ocean would vaporize enormous quantities of water. This would have a couple of effects, one of which could be to contribute to the intense rains of the Flood. Thirdly, dust and ash in the atmosphere would produce significant cold and darkness for about 3 to 5 months from the time the Flood began. Fourth, it is possible that a significant fraction of Earth's preflood atmosphere could be literally blown away by the large impact explosions. Many other local and regional geologic catastrophes would be produced by impacts, possibly including acid rain, giant tsunami waves, atmospheric density flows and unusual winds, earthquakes, and fractures penetrating all the way through the Earth's crust.

Cratering Mechanics

The important physical parameters and processes involved with crater formation explains the main reason for Earth's craters being so much smaller than the many large craters found throughout the solar system. Parameters important for the projectile or impactor are its density, diameter, mass, and speed. It is the kinetic energy that is actually the determining factor in many aspects of the calculations. And when estimates are made of the size of the impactor, what is actually done is to determine its kinetic energy. Then if a reasonable speed is assumed the mass can be calculated from the equation for kinetic energy W. Once

$$W = \frac{1}{2} m v^2$$

a mass figure is determined, the size can be determined if the density is known. The angle of approach of the impactor is usually measured from the horizontal, but for many calculations this is not significant. The bowl structure is a result of the severe compression of the target area, so the force excavating the crater (directed upward) is a reaction force to the downward impulse from the collision. Important parameters for the target are density (which is a function of temperature and time), elastic yield strength, porosity, and the acceleration due to gravity.

The acceleration due to gravity explains much of the difference in the sizes of impact craters on the Moon versus the Earth, for instance. For a given projectile of a certain mass and velocity, the crater formed on the Moon would be 5 to 6 times larger than on the Earth [14, p 122]. This is because in the excavation of the crater, work is done against gravity in pushing up the rim structure. This means that the giant Aitken basin near the Moon's south pole (2,500 Km diameter), if the same object struck Earth, would form a crater 400 to 500 Km in diameter. This should be considered a realistic upper limit for the largest possible impact on Earth. Many impact structures much larger than this exist in the solar system, but they are all on objects with gravity much less than that of Earth. Venus is close to Earth in mass and gravity and its largest craters are also in the same size range as Earth. No astroblemes are known of 400-500 Km diameter on Earth, but such a structure could have been destroyed or deeply buried by processes of the Flood or during the postflood period. The largest known possible impact sites on Earth would have a rim diameter of about 200 Km, perhaps. There is considerable debate about the size of the possible structure at Chicxulub in Yucatan. The Yucatan site is not the only possible impact site of this size. Though there would be many objects involved in a bombardment event, the number of very large objects would be so few that it would not be implausible for there to be no impacts on Earth in the 400 Km crater diameter range.

Impacts and Runaway Subduction

Dr. John Baumgardner has suggested that subduction of the preflood ocean lithosphere initiated the Flood and led to the rapid break up of a single preflood supercontinent during the Flood [5, p 63]. This model, known as Catastrophic Plate Tectonics, suggests that the main driving mechanism for many Flood processes was the subduction of the preflood ocean lithosphere. The subduction of the ocean floor material would require two conditions to allow the subduction and mantle convection mechanism to start. First the ocean lithosphere would have to be colder and less dense than the continental lithosphere in order to give it a natural tendency to sink. Second, some physical process would have to cause two mineralogical solid state phase transitions in the region from about 400 Km depth to 660 Km depth. The olivine and spinel silicates would need to be stimulated to undergo atomic rearrangement such that their density would increase. This is possible in this region of the mantle because at 410 Km depth olivine is rather unstable but the beta-spinel form is stable. Similarly, near 660 Km depth the spinel silicate crystals become less stable but perovskite is stable. A significant mechanical shock of approximately 10^7 to 10^8 Pascals would be sufficient to cause crystal nuclei to form for the denser phases [4]. Baumgardner has suggested that "an impact of modest size" would be able to stimulate this mineral phase change and trigger subduction [5, p 74]. One impact, however, would only produce the necessary shock pressure in a limited volume of the mantle just under the impact site. With one impact there would be no plausible mechanism for producing the phase change over a large enough volume. If the phase change occurred over large volumes of the mantle due to many impacts occurring simultaneously all around the world, the ocean lithosphere would be stimulated to sink. Impacts would therefore provide a plausible trigger mechanism for catastrophic plate tectonics.

To determine if large impacts could indeed create sufficient shock wave pressures to initiate the mineralogic phase transition, the work of H. J. Melosh on shock wave attenuation with depth was applied [14, p 63]. The attenuation of impact shock waves with depth involves complex physics. The estimates that follow are only to be considered order-of-magnitude estimates. Melosh's example represents a case of an iron meteorite striking target rock composed of gabroic anorthosite at various speeds from 5 Km per second to 45 Km per second. Theoretical scaling considerations, elastic properties, and thermodynamics all go into the following relations. What is important is pressure as a function of distance r from the center of the crater; this distance is essentially the depth below the impact point. From a depth of 1.5 to 3 projectile diameters the pressure attenuates rather slowly in the region where there is strong compression and melting of the target material, dropping off in a manner proportional to $r^{-1.5}$. Then with greater depth the attenuation changes to r^{-2} to r^{-3}, depending on the speed of the impactor. This steeper drop-off in pressure persists to depths of about 20 projectile diameters. In this region the rock and mantle material is being shocked or fractured and the pressure is greater than a level known as the Hugonoit Elastic Limit (HEL). At around this pressure level, as the shock wave continues downward below the impact, the pressure attenuation changes again to a slower drop-off, proportional to r^{-1}. At this depth, the material behaves as an elastic solid or semi-solid.

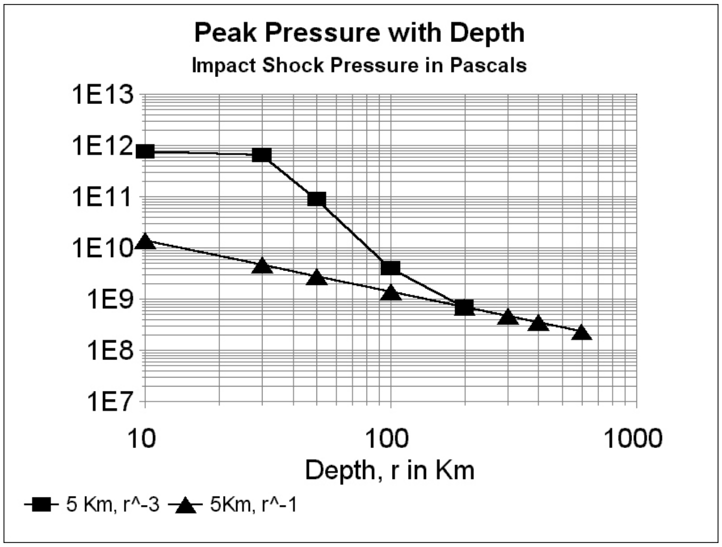

Figure 1 Adapted from Melosh. Square marked line shows the three different pressure regimes in how shock wave pressure is attenuated with depth. Triangle marked line shows the pressure attenuation for regions of great depth.

Melosh's analysis was summarized in a graph constructed in a way that could be applied to various sized objects and depths. Melosh's work was constructed to show the peak shock pressure at depths above the 400 to 600 Km region which is important for this discussion. Melosh's graph only showed a part of this region. So, one of his curves has been reproduced and shown on a somewhat different scale to allow it to be extrapolated downward to greater depths. The pressure attenuates with the inverse depth (r^{-1}) in the 400 to 660 Km depth region. Thus, the following graph (Figure 1), of peak pressure as a function of depth is a reproduction of Melosh's graph. Figure 1 shows depth figures for a meteoritic object 5 Km in diameter. The slopes of the lines show the different power law pressure decay relationships, since the graph is a log-log scale plot. Note that the straight line with triangle markers shows the pressure attenuation in the 400-660 Km depth region.

The next graph, Figure 2, expands the bottom portion of Figure 1, displaying the pressure curve for several sizes of projectiles. Capital "R" represents the projectile radius and lower case "r" represents the depth. To initiate subduction, the shock wave must increase the pressure by about 10^7 to 10^8 Pascals above the ambient pressure, which is on the order of 10^{10} Pa. Thus the shock wave produces a brief pulse of higher pressure that causes the silicate minerals to rearrange and compress into a smaller volume. Figure 2 implies that a 2.5 Km radius or 5 Km diameter object would be the minimum

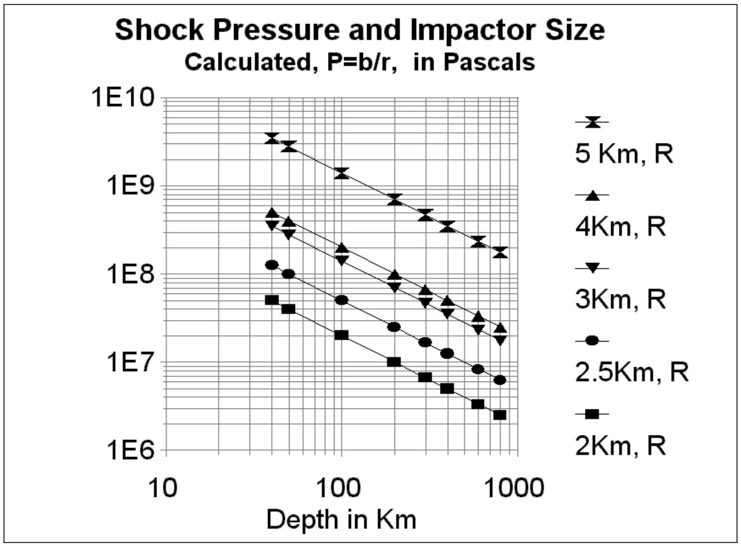

Figure 2 Impact shock wave pressure as a function of depth for various sizes of impactors. Adapted from Melosh.

size necessary to produce an adequate shock wave. This is not a very precise figure, however, since the kinetic energy is really the determining factor, not the size of the object (see equation above for W).

Atmospheric Effects

The energy in large impacts is very difficult to imagine. It is important to understand what happens to the energy in such a high speed object. Meteoritic objects striking Earth could be expected to be traveling at speeds in the range of 20 to 40 Km per second in most cases, however comets could travel at greater speeds. The energy in a large impact would dwarf the explosive energy in all known volcanic eruptions and nuclear explosions. The largest natural volcanic explosion is Krakatoa, whose explosive energy has been estimated at 10^{24} Ergs (10^{17} Joules). The largest nuclear test was a 58 Megaton explosion conducted by the Soviets in 1961, with an energy of 2.5 X 10^{24} Ergs [12, p 175]. But the energy in a one kilometer diameter rocky object entering Earth's atmosphere would be approximately 4 X 10^{27} Ergs (4 X 10^{20} Joules), over 1000 times the energy in the largest nuclear weapon test! When an object strikes the Earth's surface, all but a small percentage of the energy is deposited into the target material. This energy is used up in fracturing and melting rock, displacing material into the crater structure, and vaporizing material. When an object does not reach the surface but breaks up or explodes in the atmosphere, it deposits most of its energy into the atmosphere rather than into surface material. Thus for atmospheric meteor explosions the atmospheric shock waves are more intense than if the same object struck the surface. Large impactors that strike the ocean would vaporize large amounts of water as well as put dust and ejecta into the atmosphere. I would expect the amount of water vaporized to be on the order of 10^{15} to 10^{17} kilograms [6].

The large amounts of water vapor ejected into the atmosphere by impacts would clearly contribute to the rains during the Flood. Genesis 7:11-12 describes the 40 days and nights of rain that was apparently very intense. But not until Genesis 8:2 is the rain said to have stopped. It seems the initial 40 days included especially intense, probably global rain, but rain continued perhaps occasionally in a more limited way until about the 150 day point, approximately. This may suggest two types of processes producing the rain, one that was especially intense for 40 days and another which continued for a longer time, but in a less intense way or in a manner less than global. The vaporization of large quantities of water at the onset of an impact bombardment could be a source of water for the 40 days and nights of rain. This is not the only possible source of water for the rains. Steam explosions would be produced at the ocean floor spreading centers during the rapid plate tectonics outlined by John Baumgardner. Water injected into the atmosphere by the tectonics process could be expected to continue for as long as subduction and mantle convection occurred, whereas impacts would generate an initial intense surge of rains which would subside as the number of impacts dropped off. It is also important to note that even impacts into the ocean would eject dust into the atmosphere as well as water.

Much has been learned from research related to the atmospheric effects of dust produced by a 10 Km diameter object. The Alvarez impact-extinction hypothesis suggests a 10 Km diameter object would possess a kinetic energy of about 10^{29} Erg, which would be equivalent to 2.5 million megatons of TNT explosive. (1 Megaton = 4.2 X 10^{22} Erg or 4.2 X 10^{15} Joules.) Another way to express the energy from a 10 Km object would be that it is approximately equivalent to 250,000 Mt. St. Helens eruptions [25, p 189]. An object of this energy would deposit tens of thousands of megatons of energy into the atmosphere, primarily in the form of the expanding vapor plume, but also from solid and melted material ejected into the atmosphere. Large impacts would propel very large quantities of dust (and water if taking place in the ocean) into the stratosphere. The Alvarez impact extinction mechanism relies completely on the atmospheric and climatic effects of large amounts of dust and other material ejected into the Earth's atmosphere. The stratosphere is heated as a result of the dust but this heat is not felt at the surface or in the lower atmosphere. An "impact winter" phenomenon, similar to "nuclear winter" would ensue as a result of the dust and its effects in the stratosphere. Darkness and cold over a period of a few months are the primary mechanisms relied on by the Alvarez team for causing extinctions. All other effects of impacts near the surface are local or regional in scope, not global. This has been alluded to by researchers modeling the atmospheric effects of impacts, such as the following quote of Steven Croft, from the Lunar and Planetary Institute (emphasis is his):

> The fraction of the earth's surface, and hence biota, *directly* affected by even a relatively large impact producing a crater on the order of tens to hundreds of kilometers in diameter is relatively small. This, coupled with the (equivocal?) paleontological evidence that the C-T extinctions occurred over a period of time, implies that any global/long term effects associated with such impacts are largely climatological [6, p 143].

Atmospheric effects are an important matter to consider in relation to a bombardment event coinciding with Noah's Flood. If the time frame of the atmospheric effects is too long or too severe, it would not be consistent with the Biblical account and would therefore be ruled out. The evolutionary approach to Earth history has a strong vested interest in claiming severe global environmental effects from one impact, since it is considered by some to be the best tool evolutionists have for explaining extinctions. This strong reliance on one impact is unreasonable and the result may be to exaggerate the environmental and biological consequences of a large impact. Impact physics can tell us something of the physical effects of such events, but to judge the biological or environmental consequences is far more uncertain.

Having only one impact leads to a problem for the Alvarez hypothesis in the atmospheric physics of the event because the dust needs to be distributed world-wide in the stratosphere very quickly, such as in a matter of half a day or less. For one impact this distribution of dust may not be rapid enough. The result would be regional effects instead of global effects. Atmospheric density flows and dust coagulation would lead to more rapid depositing of the dust in certain regions at the surface rather it staying in the atmosphere longer in order to produce the long darkness and cold required for extinctions. However, if there were a major bombardment event with a significant number of large impacts around the world simultaneously or nearly so, this would distribute dust globally in the stratosphere very efficiently and quickly. The effect would be to evenly spread out the dust in the stratosphere, which would tend to keep the dust in the atmosphere longer. If the dust is not evenly distributed in the atmosphere, atmospheric density flows would move dust downward through the atmosphere in a dramatic fashion due to coagulation of the particles, and this would move dust to the surface more rapidly than if it undergoes normal settling in the atmosphere. Some of these density flows would undoubtedly occur and their effects are impossible to predict mathematically in atmospheric models. A very important paper studying these atmospheric effects comments as follows:

> Hence, such meteoritic mass loadings represent substantial increases to the atmosphere mass. Increased atmospheric mass would create hydrodynamic density flows like those observed on the slopes of volcanoes, and the debris would rapidly flow to lower altitudes and also spread horizontally. We believe that unless the ejecta is transported ballistically, or by impact-induced flows to distances well beyond 1,000 km diameter, substantial quantities of debris will not remain in the atmosphere [25, p 194].

Thus, dust must be rapidly distributed in the atmosphere or the climatic effects will not be severe enough or global in nature. Significant quantities of dust and tektites would also be lofted above the atmosphere into long ballistic trajectories that could distribute the material hundreds of miles or more from large impact sites. The implication is therefore that a bombardment event with many impacts could do what evolutionists have unrealistically proposed that one impact would do.

Explosive eruptions of volcanic ash are also capable of ejecting large quantities of dust into the atmosphere, but there are some important differences between volcanic eruptions and impacts. In volcanic eruptions, both particulate and gaseous matter are input into the atmosphere. Silicate volcanic ash falls to the surface in only a few months but the sulfur dioxide and other gases from a volcano form sulfuric acid and aerosols which will linger in the atmosphere for longer periods, such as a year or more. Even the largest known volcanic ash eruptions, including Tambora in 1816 for instance, would eject a volume of particulate material much smaller than a large 10 Km diameter asteroid, for instance. Also, in impacts, the dust would be propelled much higher in the atmosphere than volcanoes are capable of. As a result, volcanic eruptions are not good analogs for impacts since volcanic eruptions would not have the dramatic effects on the stratosphere which impacts would have. The paper by Toon et. al. comments:

> The spread of volcanic debris probably is not a good analog for a large meteorite impact. . . . A good analogy to the spreading after an asteroid impact may be the rapid spread of Martian dust storms. The atmospheric mass on Mars is comparable to that of the Earth's stratosphere above 30 Km. . . . The models show rapid expansion driven by radiative heating in the dust which induces a strong circulation. We conclude from the volcanic analogy that asteroidal dust is not likely to remain in the stratosphere more than a few months. . . .Debris from a large asteroid impact would probably induce a stratospheric wind system tending to quickly spread the debris over the Earth. This dust spreading would be more similar to Martian dust storms than to volcanic events on Earth [25, p 190].

In Genesis 8:1, the text mentions a wind that God caused to pass over the earth that made the waters subside. The effect of the impact dust in the stratosphere would be to produce strong stratospheric winds, possibly global winds. If these winds continued for periods of months, there is a possibility they could eventually produce winds at lower altitudes. Thus, the impacts might provide an explanation for this interesting reference in Genesis, though this possibility should be investigated further by creationists in the atmospheric sciences. After subduction of the preflood ocean lithosphere had continued for some weeks, the ocean would be quite warm, a wind would increase evaporation of ocean water and decrease the waters depth.

The impact dust's behavior is governed by sedimentation in the atmosphere and coagulation. Many particles would be approximately 0.5 micron in size initially. Solid particles of this size are very efficient in sticking together upon colliding with each other, according to experimental studies [25, p 191]. Particles of 0.5 micron diameter may require a year to fall to the surface of the Earth, but this is assuming no coagulation. The more dust is ejected into the atmosphere, the greater the dust density in the atmosphere and the more rapid the coagulation. Thus, in an event in which there are many impacts in a short time, the coagulation would be more efficient and would tend to remove many of the particles from the atmosphere more rapidly. On the other hand, coagulation efficiency has only a minor effect on the time required for the dust to fall to the surface. In fact, even the total mass of dust does not affect the time of fall very strongly. Winds and atmospheric density flows as well as the atmospheric density of dust particles are the most important factors in the time for the dust to fall. Thus, an amount of dust much greater than that produced by one 10 Km impact would still take about the same amount of time to fall to the surface. Certainly some particles would persist in the atmosphere for years, but most of the particles would be removed in times of 3 to 6 months.
The optical depth of the atmosphere is an important measure of how transparent or clear the atmosphere is in such events. This has been studied by Toon, et. al. An optical depth of 10 corresponds to a cloudy day and would be barely enough light for photosynthesis to operate. A value of 20 would probably make photosynthesis impossible and values of 20 to 30 would correspond to a moonlit night. Toon et. al. again summarize their conclusions from their atmospheric models of the dust:

> The physics is dominated by coagulation and sedimentation so that the duration of the event is not sensitive to most of the initial conditions and atmospheric parameters. The duration of large optical depths is probably shorter than 6 months and is most likely less than 3 months. It is highly improbable for substantial quantities of debris to have remained in the atmosphere for more than a year [25].

These studies were for one impact, considering different types of impactor objects, speeds, as well as target materials. If many impacts occurred at the same or nearly the same time, the dust fall time would likely be longer than the 3 months sited above. Times of 4 to 5 months seem very reasonable for the lower light levels. After this amount of time, the atmosphere would be clearing but cold temperatures would continue for some weeks. A consequence of the dust is that the dust reduces the planets albedo, causing the Sun's radiation to strongly heat the stratosphere rather than penetrating to the surface. Thus, the darkness or near darkness would lead to cold ambient temperatures in the lower atmosphere, possibly even well below zero by the atmospheric models. In the time the optical depth is greater than 10, the ocean would only cool by a few degrees but the lower atmosphere would very likely drop below freezing. It has been estimated that the low temperatures last about twice as long as the low light levels [25, p 196-197].

The great quantities of water vapor put into the atmosphere are a significant unknown in terms of what effects it would have on the global average temperature. Much rain and possibly even some snow could result from the large quantities of water vapor in the atmosphere. The water vapor from ocean impacts would certainly supersaturate the stratosphere with water vapor. Water is also an effective greenhouse gas, so after the atmosphere began to clear, water could produce a greenhouse heating effect than could moderate the cooling effect of the dust. Atmospheric density flows and rain (at the lower altitudes) removing dust from the atmosphere could also reduce the severity of the darkness and cold. Other effects significantly complicate these issues, such as the possible loss of the ozone layer, photodisociation of water, changes in Earth's magnetic field, etc. At present there is no detailed model for the changes in Earth's atmosphere during the Flood that creationists broadly agree on. There are several opinions on the nature of the preflood atmosphere and how it differed from the present atmosphere. This is beyond the scope of this study. One thing is clear however, that creationists must consider the major consequences impacts will have on atmospheric models related to Noah's Flood.

Another possible effect of large impacts on the atmosphere is a phenomenon that has been described as atmospheric blowout. The vapor plume from an impact will rise rapidly up the partially evacuated column just above the impact point, then begin to expand upward and also into the direction of motion of the impactor object. The vapor cloud will expand and rise in the atmosphere until its density becomes the same as that of the atmosphere. For large impacts the vapor plume may expand at a speed greater than the planets escape velocity and it may never match the atmosphere's density. This means that the vapor plume will literally blow away some of the atmosphere into space. This process would carry some solid particles, tektites, into long ballistic trajectories carrying them hundreds of miles from their source crater. Melosh has applied this mechanism to the atmosphere of Mars [15]. He proposes that during the late-heavy bombardment period 4.5 to 3 billion years ago, the intense impact bombardment blew away most of Mars' early atmosphere, leaving it with a thin atmosphere as it has today. Melosh's approach implies that Mars would have began with an atmospheric pressure about the same as that of Earth today, which is about 100 times Mars present pressure. Melosh's approach is an attempt to explain how Mars could have had a heavier atmosphere in the past that would have allowed for liquid water on the Martian surface. Melosh points out that applying the same calculations to Earth implies Earth would have had a pressure 6 times the present value after it formed. Then impacts blew some of its atmosphere away, before life evolved, to make the pressure what it is today.

This blowout effect, could apply in a less extreme way to Earth during the Flood. Melosh applies accepted mathematical models on Earth's impact flux history which depends on crater statistics and questionable long age assumptions. Crater statistics are based mainly on study of Lunar craters, Lunar stratigraphy, and radiometric age determinations done on Moon rocks. The relative order of the Moon's lava flows and craters is correlated with radiometric age dates to arrive at a graph showing crater density as a function of age [15, p 488], or sometimes shown as cratering rate as a function of age [24, p 86]. Points are plotted on such graphs using radiometric age dates and then areas under the curves are determined by some form of mathematical integration to get a cummulative total number of impacts. Assumptions are made in these statistical analyses that are probably flawed. Using the area under such a curve to obtain the number of impacts assumes that there were actual objects that existed which represented each point under the plotted curve. If the impactor object population was more "spotty" and not a slow steady impact rate, there could be significant areas under these type of fitted curves which would not be represented by actual objects. These considerations would imply that some estimates of the number of impacts on our Moon are too large because they depend on radiometric dates and crater statistics and not on actual craters that now exist. Lunar crater statistics have provided the basis for much research regarding cratering and age determinations of surface features throughout the solar system.

When a portion of a planets surface has a sufficient number of craters in a certain area, it can become saturated. This is a function of crater size and means that one more impact would destroy at least one existing crater. Thus, the density of craters observed in a saturated area would not change significantly after it reaches the point of being crater saturated. An area may be saturated with one size range of craters and not saturated with another size range of craters. If an area is saturated, there is no way to tell the difference, from crater counting alone, between a case where it received just barely the number of impacts necessary to saturate it and a case in which it received 100 times the number necessary to saturate it. Since some areas of the Moon and other objects in the solar system are saturated there is no certain means of knowing how many impacts occurred in those regions. The conclusion then is that the number of impacts that have affected the Moon, Earth, Mars, and other inner solar system objects could be less than accepted estimates. From a creation point of view, the late-heavy bombardment never happened. Instead, a less severe event happened later around the time of the world-wide Flood described in Genesis.

How do crater counting considerations relate to the atmospheric blowout effect? If the impact bombardment striking Earth were as intense as that used by Melosh, no one could survive on the planet. But, if a less severe bombardment event occurred then such an event could be consistent with the Biblical account in Genesis and could explain Earth impacts in a young age time frame. The total number of impacts in such a bombardment event is an important parameter for estimating the various atmospheric consequences of the impacts. It seems possible that Earth's preflood atmosphere could have had a higher atmospheric pressure than present, regardless of whether there was some kind of preflood vapor canopy. A vapor canopy may have been a relatively small amount of water that would not have added to atmospheric pressure significantly. Or, there may have been no vapor canopy in the preflood Earth. A higher atmospheric pressure has been suggested to have biological advantages by some creationists but there is not general agreement on this question. The atmospheric blowout effect could make it possible to have a higher preflood pressure, which was partially lost as a result of the impact bombardment. In this scenario, the blowout effect itself would not change the relative abundances of the various atmospheric gases. The gases would be blown out in an indiscriminate manner. However, it is also possible that the number of large impacts capable of causing blowout could have been too few to significantly change Earth's pressure. More research needs to be done to estimate the necessary number of impacts to explain both Lunar and Earth impact evidence.

Many other catastrophic effects of an impact bombardment occur on local and regional scales rather than global. This study will not discuss all the possible local and regional effects. What is of interest here are effects relevant to the question of whether an impact bombardment could agree with the Genesis account of Noah's Flood. One atmospheric effect not mentioned thus far is the effects of the passage of the projectile through the atmosphere. A bow shock forms behind the impactor as it passes through the lower atmosphere. For objects traveling at sufficient speeds, such as 20 Km per second and faster, there may not be time for the bow shock to dissipate before the object strikes the surface. The atmospheric drag on the object would probably cause many smaller projectiles to break up or possibly even explode as it passes through the atmosphere. There will be a column or tube of partially evacuated air with a layer of hot gases around it reaching essentially all the way through the atmosphere behind a large impactor projectile. The air immediately next to the projectile is heated to very high temperatures, on the order of tens of thousands of degrees. These are sufficient temperatures to dissociate water, nitrogen gas, and oxygen gas molecules. The dissociation of these molecules may lead to the formation of nitric acid rain in the vicinity of the impact. Other chemical effects on the atmosphere are possible, but very difficult to model or quantify.

Relating an Impact Event to Genesis

At this point there is no detailed model of the impact flux during the bombardment period. Presumably, the bulk of the impacts would have occurred in a period of weeks at the beginning of the Flood and the number of impacts would trail off thereafter. As the impacts began, within 1 day great amounts of dust would be distributed throughout the stratosphere and the subduction of the ocean lithosphere would begin about the same time or shortly after. While volcanic eruptions occurred in various places and intense rain began to fall, the light level would decrease and then the temperature would drop. There is significant uncertainty in the magnitude of the temperature drop. The darkness would continue for 4 to 5 months, and some measure of cold temperatures would continue for a time beyond that.

Could this be consistent with the Flood chronology? To answer this, it is necessary to go to Genesis and consider the timetable of events. The Flood in Genesis can be considered to begin with the breakup of the "fountains of the deep" in Genesis 7:11, and Noah and his family enter the Ark that same day. Genesis reports that this particular day was the 17th day of the second month of the 600th year of Noah's Life. Later on, in Genesis 8:4, the Ark is reported to come to rest on the mountains of Ararat on the 17th day of the seventh month. Thus, it was five months to the day from the onset of the Flood until it came to rest on Ararat. It is interesting that there is no information in Genesis regarding what Noah was able to see or hear from outside the Ark during this time period. There is also no description of their daily life in the Ark during this time. There is no reference to Noah being able to see anything outside the Ark until in Genesis 8:5 where it says that the tops of other mountains became visible. When they could see the other mountains, it had been approximately seven and one-half months from the beginning of the Flood. After an additional 40 days from when they saw the mountain tops, the raven was released and the dove was released for the first time. When the birds were released from the Ark it had been close to nine months from the day the Flood began.

It is not difficult to see how an impact event could fit into this timetable, if one is willing to allow for the possibility of darkness and cold during the early weeks of the Flood. There would be ample time (7 and ½ months) for most of the asteroidal dust to fall out of the atmosphere before Noah was able to see the other mountain tops. The olive leaf brought back to the Ark presents an interesting test of the compatibility of such an impact event with Genesis. The dove was released from the Ark the second time 7 days after it was released the first time. It returned that day with the olive leaf. There were 47 days from the time other mountains were no longer covered with water until the day the dove picked the olive leaf. This implies that the olive tree began growing on the top of one of the other mountains soon after that area was no longer covered. Conditions could not be too dark or cold to allow the olive tree to grow during that 47 days. But the sky would have largely cleared and returned to nearly normal light levels 2 and ½ to 3 and ½ months before the other mountians were seen. Then in this period before the other mountains were seen, the ambient temperatures would begin to rise. By the time the dove brought back the olive leaf it is plausible based on impact atmospheric models that the temperature may have returned to more normal temperatures that would be more beneficial for the growing olive tree. Thus, the global atmospheric effects of a major bombardment event are consistent with the Genesis Flood chronology.

Would an impact bombardment event be a survivable event for Noah and the others in the Ark? The atmospheric effects would make it uncomfortably cold in the early weeks of their stay in the Ark, just how cold is unknown. Atmospheric models predict temperatures well below zero, Celcius. However, these models do not account for a possible major greenhouse effect from the water ejected into the atmosphere. Other aspects of the event could make Noah and his family, as well as the animals, uncomfortable. If a large impact struck very close to the Ark, it would not survive and those inside would certainly be killed from the pressure and temperature of the air shock wave. However, that is a near field effect. As long as Noah and his family were not too close to a very large impact they would be able to survive. The likelihood of the Ark being close to a large impact depends on the number of large impacts, which will be discussed in the next paragraph. They would however, have felt the Ark tip and turn dramatically from large tsunami waves generated by distant impacts into the global ocean. The stability and seaworthiness of the Ark has been written about elsewhere by creationists [11, 16]. It is reasonable to assume the Ark could survive. Of course, the details of the Ark's construction are not known, therefore no exact calculations can be done on what forces would be required to break the Ark into two. This may be worthy of further engineering mechanics studies.

With many impacts occurring around the globe, what is the likelihood that the Ark would close enough to an impact to be at risk? We could assume there were 100 large impacts of projectiles 1 Km diameter and greater. Objects of this magnitude would produce atmospheric blast waves that could be felt tens of kilometers away from the site. Assume that a circle of 161 Km radius (100 miles), measured from the impact center, would define an "at risk" area. The Earth's surface area is approximately 5.1×10^8 Km^2. The total area of 100 circular zones 161 Km in radius would be 1.6×10^7 Km^2. Dividing these areas implies a 3 percent probability of the Ark being within one of the "at risk" zones. Of course, this is a very simplistic calculation and many other factors enter in such as the distribution of impacting objects, ocean currents, etc. However, this seems to imply it is plausible that the Ark could reasonably be expected to survive such an event. Of course there are important spiritual considerations as well. There are many possible ways in which God could have intervened in some way to protect the Ark.

CONCLUSIONS

These considerations indicate that Noah and all with him in the Ark could possibly have survived a major impact event during the Flood and that such an event could be consistent with the timetable of events from Genesis. A impact bombardment could perhaps also help explain other phenomena mentioned in Genesis regarding the Flood, such as the 40 days of intense rain and the wind mentioned at the end of the Flood account. A solar system catastrophe producing a large number of impacts on Earth in a short time during the Genesis Flood is a realistic possibility. This could explain evidence for impacts on Earth throughout the geologic column. Some craters and astroblemes would be from post-flood impacts as well, and it is possible some impacts could be unrelated to the solar system catastrophe.

This provides creationists with an alternative to the Alvarez dinosaur single-impact extinction hypothesis. The Alvarez hypothesis is clearly unacceptable to creationists even though evidence for impacts on Earth is undisputable. In my opinion one impact could not cause extinctions globally. An impact bombardment event can be understood as an aspect of God's judgement on the preflood world. Suggesting such a bombardment episode does not provide a "natural explanation" for all the effects of the Flood. The goal here is to explain Earth impacts, not provide a natural cause for the Flood. Impacts do not generate long lasting lateral forces for moving continents, but it is quite possible that impacts were occurring while continents were separating. Furthermore, shock pressure waves generated by impactor objects of at least 5 Km diameter would be sufficient to stimulate solid state phase transitions in the 400-660 Km depth region which could trigger ocean lithosphere subduction as outlined by Dr. John Baumgardner. There is evidence that impacts were occurring simultaneously with volcanism since both impact shock minerals and volcanic ash have been found together in sea floor sediments [21]. The global effects of large impacts are due to dust in the stratosphere increasing the optical depth of the atmosphere and decreasing the light levels. Cold temperatures in the lower atmosphere result from light and radiation not reaching the surface. The low light levels and cold temperatures would not be too severe or too long in duration to prevent Noah, his family, and the animals from surviving in the Ark. Though impacts would add to the violence of the Flood event, they should be an advantage to creationist earth scientists refining models of the Flood.

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