4- The Cosmic Serpent

The Cosmic Serpent is a scientific book that discusses the asteroid impacts on the earth and other planets. It contains the most detailed and complete information in one volume. It appears that some of the events in the Book of Revelation are direct results of impacts of meteors or asteroids. The destruction in Third Nephi seems also to fall into this type of natural disaster.

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It turns out that if the current population is typical, an Apollo asteroid of at least 1 km diameter will collide with the earth every 250,000 years or so. If such an asteroid has the density of water ice, its mass is 4 billion tons and for a mean impact velocity of 25 km/sec the impact energy is **3 million megatons**. For a rocky constitution the energy will approach **10 million megatons**. The unit of energy employed here is the "megaton equivalent of TNT", one megaton corresponding to the explosion of a million tons of TNT. The Hiroshima explosion had an energy of about a fiftieth of a megaton; (1/50 of 1 megaton) a sizeable hydrogen bomb will release 1-10 megatons of energy; the Krakatoa eruption of August 1883 was about 50 megatons; and a major earthquake may involve the release of over 100 megatons.

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The effect of a large land impact

The comet or asteroid will enter the atmosphere at hypersonic speed and a shock wave will hug its forward hemisphere and extend backwards as a long cylinder. Essentially it punches a hole in the atmosphere, the displaced air being thrust sideways from the cylinder at about the speed of the missile, creating a blast wave of about 10 million megatons. The great bulk of the kinetic energy of the asteroid therefore reaches the ground, and the crater develops in the manner already described. Much of the energy is expended in the fragmentation and shifting of the rock, a few per cent going into the creation of a high-temperature ball of vapour. A crater of about 200 km diameter is formed within a few minutes, ejecta being raised through several kilometers and deposited in part in a rim. The atmosphere around the crater will be violently disturbed by these rapid ground motions and by the expansion of the fireball. Further, the passage of ejecta ranging from kilometer-sized lumps to hot ash is expected and strong interaction will occur between these ejecta and the atmosphere. The proportion of energy ultimately deposited in the atmosphere is difficult to assess with precision. Certainly in an explosion, a considerable percentage of the original energy ends up as blast wave. A figure of 10 per cent is adopted below.

Complicated though the atmosperic disturbances must be in the region of the crater, the situation will have simplified within a few crater diameters, a few minutes after the explosion. Beyond 1,000 km, say, from the epicentre, a shock wave will have formed and be moving rapidly outwards. The situation may be characterized by a cylindrical shock front behind which the atmosphere has piled up into a dense, high-pressure hot shell. The shell snowploughs into the as yet undisturbed atmosphere ahead of it, gathering it up. If say 10 per cent of the impact energy is deposited as blast motion into the atmosphere within 500 km of the epicentre, then at 2,000 km distance a wind velocity of 2,400 km/hr of characteristic duration 0.4 hr is expected. If there is no back pressure behind the blast, that is if it is impelled forwards simply by its own momentum, then at 5,000 km

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the wind velocity has dropped to 400 km/hr, enduring for 0.8 hr, and at 10,000 km from the epicentre, that is 90 degrees away, the wind speed is down to 100 km/hr and blows for 14 hours.

In addition to the dynamic pressure caused by the blast of air there is an instantaneous pressure and temperature rise due to the compression of gas immediately behind the shock front. The shock and blast inevitably deposit energy into the atmosphere, and this appears ultimately as heat. At 2,000 km the overpressure is 8.5 atmospheres and the air temperature is 480 degrees C. At 5,000 km the figures are 0.6 atm and 60 degrees C, dropping to 0.1 atm and 30 degrees C at 10,000 km. This intense heating expands the atmosphere behind the front, which rises to create a hot, low-density regime: the blast wave is thus followed by a partial vacuum, a rarefaction wave, of somewhat longer duration.

If all the nominal 100 million megatons of energy deposited in the atmosphere were manifested as wind motions, a mean wind velocity of 1,500 km/hr would be expected globally. If deposited as heat, then a global rise in air temperature of 43 degrees would be expected.

The heat-deposition problem is somewhat complicated by the fact that vaporized and melted rock, hot ash and so on will be flung out of

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the crater, the vapor and small particles especially streaming along with the current. This represents an additional source of heat, but the consequences are difficult to assess.

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About 100,000 cubic km of material is ejected by the impact, much of it in the form of fine dust, which is carried along by the violent motions of the atmosphere. Even in an undisturbed stratosphere, fine dust quickly spreads globally.

The falling speed of a particle ten-millionths of a centimetre across in the normal, undisturbed atmosphere is about 1 mm/sec at 50 km altitude, about 0.1 mm/sec at 30 km, and about 0.01 mm/sec at 15km. At the latter speed a falling time of five years is implied. Very roughly a particle a tenth as large has a tenth this falling speed and the converse. Sub-millimetre-sized particles would fall out within about a month.

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A similar proportion of 100,000 cubic km would result in a blockage of sunlight with an Aoverkill@ factor of over 10,000 ! Thus, if this simple picture of dust suspension were valid, total blackness would be expected for two to three years after the impact, followed by a rather sudden clearing of the sky.

A drastic change in the chemistry of the atmosphere, probably of most consequence in the stratosphere, is also likely. Above about 2,000 degrees nitrogen and oxygen in the atmosphere combine to give nitric oxide. Each megaton injected into the atmosphere will produce between 1,000 and 5,000 tons of nitric oxide and this will be carried into the stratosphere. An injection of 100 million megatons therefore implies the creation of several hundred thousand million tons of NO. Between 15 and 40 km altitude, ozone (03) filters out biologically damaging ultraviolet solar radiation. The mass of ozone in the atmosphere is comparable with the injected mass of NO. The latter however, destroys ozone by a catalytic reaction in which 1 g of NO removes 100-200 g of ozone. The result of the impact would therefore be a complete removal of the ozone. While this hardly matters when sunlight is blocked by dust in any case, the question would become important if, by the time the dust clears, the ozone were still depleted. The timescale for the replenishment of ozone is twenty to thirty years.

Apart from these atmospheric effects, mention should also be made of a ground effect which may be of consequence well beyond the crater. The energy carried by the shock, penetrating the ground, shatters and heats the rock, expelling some of it to form a crater. But a small residue of this energy will spread beyond the rock-fragmenting region: once the tensile strength of the rock is greater than the shock pressure, the rock no longer fragments and the energy is transported by vibration. Probably 1 per cent or so of the total energy is thus carried away by seismic waves. For the impact being discussed, about 10 million megatons will go into these vibrations much of it as surface waves--earthquakes. The Rayleigh (corkscrew) and Love (to and fro) waves which comprise earthquake motions damp slowly with distance, the amplitude at 5,000 km still being a third of that near the epicentre; and at 90 degrees from the impact point the energy/km squared in the ground motions will still exceed 10 percent of that around the crater. A mean global value of about 0.01 megaton/km sq. Is implied. This is at the extreme top end of earthquake intensity scales, and corresponds to great catastrophe with for example earth layers being overturned, clefts appearing in the ground and free-standing objects and creatures being thrown in the air.

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To sum up, the immediate global effects are a violent scorching wind, the ejection of incandescent material, severe earthquake, possible a prolonged obscuration of sunlight, and exposure to ultraviolet radiation of germicidal intensity when the sky clears.

The effect of a large oceanic impact

Of course most impacting bodies will have crashed into seas or oceans. The consequences of ocean impact have been little studied and are not well understood, and in the description that follows one cannot even be sure that all the main features of the phenomenon have been included.

Experiments on crater formation in sand show that the sizes of craters in loosely bound material may be up to ten times those of the corresponding craters formed in rock. A very large, shallow crater, perhaps 500-1,000 km across, would be formed by the impact of a 10 km diameter asteroid, the crater "walls" being formed of water. The whole structure, because of the great dimensions, would take over an hour to form. Of course the ocean whose depth will be less than the diameter of the asteroid, is quite unable to absorb the impact momentum and a true crater will be formed in the sea bed, breaking the crust and exposing the underlying hot mantle material. The shattering of the ocean bed material will not be greatly affected by the overlying water but its excavation will be; in effect some of the ballistic energy of excavation will be transferred into water wave motion. Lifting and displacement of the underlying rock may be a prime input to the oceanic disturbance.

The filling in of the water crater will create a rebounding column of water mixed with solids, the whole reaching several kilometres in height. Because in the latter stages the inrushing water is flowing over lava some energy transfer is expected. It might be considered that a square centimetre column of water several kilometres deep will not be significantly affected by heating through contact with lava at one end; however the possibility exists that some of the heat energy is expended in overturning the lave, in which case a rapid convective mixing of the lava is possible. The heating then becomes a volume rather than a surface phenomenon and may be quite significant. The energy contasined in a 100-metre depth of lava a 2,000 degrees C, in a crater of radius 100 km, is about equal to the initial impact energy, and this must complicate the subsequent flow of the displaced water. We neglect the effect here.

The crater expert Gault and his colleagues carried out a calculation

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in which a 1.4 km diameter asteroid struck the ocean at 25 km/sec. They found that 92 per cent of the impact energy went into splash, shock heating and wave formation. The ocean was evacuated to a depth of 6km over a radial dimension of 15 km. Neglecting turbulent dissipation of the wave energy, they found that the "ripples" spreading outwards had an amplitude of 1 km at 100 km distance from the epicentre, droping off in proportion to distance so that, for example, the wave amplitude was 50 metres at a distance of 1,000 km.

Approaching a shoreline, a wave slows down and increases in amplitude as it enters shallow water. There is a piling up of water as the forward part of the wave slows down. An increase in wave height by a factor of ten as the coastline is reached is expected so that the 50 metre wave would become 0.5 km in height.

The important question however, is the stability of these impact-generated waves. Development of the wave structure is a complicated technical problem and work carried out by Strelitz suggests that the waves may break up and dissipate in the ocean. The reason is that the waves are steep, not sinusoidal. Piling on to each other they evolve into a hydraulic bore--an almost vertical wall of water in an extreme case--which cannot maintain its shape and therefore breaks up in the open sea.

The steepness of the waves, in turn, comes from the small dimension over which the energy has been deposited; thus in the Gault calculation one has energy greater than that of any earthquake-induced tsunami dumped into a mere 200km sq. Of ocean. A normal tsunami may be induced by a sub-oceanic earthquake covering an area of 30,000 km sq. The waves generated are of great length and are very shallow: on a ship at sea one would scarcely notice the swell. These long wavelengths tend not to be destroyed by passage into shallow water and can therefore deposit their energy right on a coastline, with devastating effects.

The situation may be quite different with an asteroid of 10 km diameter, for in that case the collision energy is a thousand times as great and the submarine crater has an area comparable to that covered by a large earthquake. Thus the ground motions which will

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couple into the overlying water will generate waves of length comparable to that generated by a normal earghquake. Of course the energy transported implies a much greater wave amplitude: 1,000 km from the epicentre, the wave would be on the order of 0.5 km in height. For a wavelength of say 100 km this still represents quite a shallow wave; pending detailed calculations or observations in the field, it seems likely that this wave energy can be transported over global distances at least until it reaches a continental shel or a coastline or a shallow sea, where it will rear up and transform into a breaker kilometres high. A run-up on to land would create a hydraulic bore of awesome dimensions, and a deep and catastropic inundation of the land.

(Victor Clube and Bill Napier, *The Cosmic Serpent*, Universe Books, New York, 1982)