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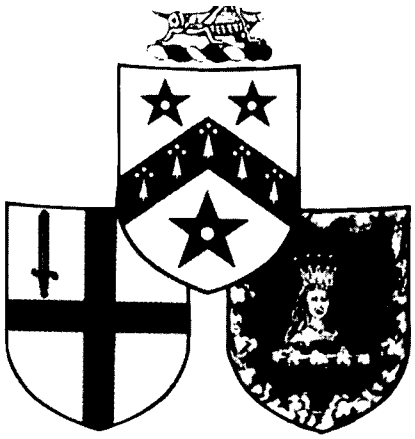

THE NATURE OF IMPACTS AND THEIR IMPACT ON NATURE

A Lecture by

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3 October 1997

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The Nature of Impacts and their Impact on Nature

Just as the possibility of stones falling from the sky was greeted with howls of derision in the late 18th century, the idea that a meteorite crater 1 km in size was located in Arizona was enough to send geologists into paroxysms, just a century later. Daniel Moreau Barringer, a mining engineer however was unpreturbed. Because one of the clues supporting the hypothesis, was the presence of nickel iron fragments in and around the crater, which would eventually bear his name, Barringer acquired the mining rights. He believed that there was a vast mass of iron below which could be exploited commercially. The engineer was to be disappointed; by 1908 he had drilled 28 times in to the floor of the crater and found nothing except large quantities of fused quartz. The conventional wisdom that Barringer was ignoring was that the crater was a volcanic vent. However the melted quartz seemed to him to completely rule out the volcano idea. He knew of no geologic process that could suddenly melt and quench quartz which does not soften until 1850°C.

By 1929, when he died Barringer he had spent $600,000 seeking his fortune at the bottom of a hole in the desert, with no luck. However, the idea that the feature was extraterrestrial had gained acceptance. And infact Barringer had unwittingly made a good living for his descendants, who for the future owned a tourist attraction beyond value.

The evidence for the existence of craters had been staring scientists in the face for as long as man existed on the Earth. You only have to look at our nearest neighbour in space and you can see craters with the naked eye. The Mare Imbrium the biggest feature on the Moon is one; the crater Coperinus another, it has a ray $>10^6$ meters long. But everyone thought these were volcanoes. Former Gresham Professor, Robert Hooke in 1667 said "they looked like bubbles in boiling alabaster". It was not until the space programme and the Apollo landings in particular that it was realised that lunar magmas were not very viscous, so they do not heap up into mountain-like piles. Every pit, pock and indentation that you can see on the Moon was caused by bombardment. Even the Moon itself was the result of an impact with spalled material off its parent planet.

The space programme showed us unambiguously how universal bombardment is. Virtually every thing in the solar system which is solid has evidence of craters. As a corollary if you see something which does not then, by default, it must be young. This is part of the logic behind the idea that Europa is being resurfaced, it has no craters therefore it must be comparatively new and an ocean covered with occasionally melting ice is a good concept. Using the Moon as a reference point, because we have real dates for the rocks, these allow ages for the sufaces of planets, we have not yet visited, to be estimated.

Impact is not only prolific, it is the most potent force in our Universe apart from the stars, and even that is debateable. The only good thing we can say about impact is that it is slowing down. The earliest impacts observed are the biggest and the phase in solar system history to coincide with this is called the late bombardment. What this means is that in the last stages of the formation of the planetary system, huge fragments of solid matter were still flying around as bodies were accreting. The energy released by these impacts were sufficient to melt planets. Some geologists argue that we can find no rocks on Earth older than about 3.9×10^9 years geological resurfacing. There are few rocks on the Moon older than 4.0×10^9 years and the Earth is a much bigger gravitational sink for stray chunks of matter than the Moon. Therefore it is probably impact which has obliterated the record. As long as the late bombardment was going on there was not chance of life developing.

Never mind about things that happened back in geological time, it is important to know to just what forces are being unleashed now by what have been called "doomsday asteroids". The energies generated are staggering. The sums are very simple to do: an object coming to us from space will have a velocity of somewhere in the region of 20-60 km/sec. This can be translated to kinetic energy by the formula $^1/_2\ mv^2$, because of the square term the number is high. When the moving object is stopped suddenly, in less than a second or two then every thing is converted to heat. The amounts of heat are not just big they are colossal. Rocks are not good conductors of heat so it is not dispersed. During an impact, they don't just melt, or even boil or more than that vapourise: the temperature rise is so high that they form a plasma - elements have the electrons stripped off them to become charged atoms. The only other place this happens is in stars and even then in estimated ceiling temperature 10000°C is higher than the surface of the sun.

To consider what this actually means in terms of known craters. The one we have heard about already, the Barringer Crater is 1.2kms in diameter. It was produced by a meteorite which was only 50 meters across. There is a pretty good rule of thumb: the size of the crater is about 20 times bigger than the object which caused it. Here however, comes the crunch, the explosion for this 50 meter metorite was equivalent to 300 times the size of the first atomic bomb dropped on Hiroshima. Going up the scale a little, the best known crater in Europe is in Southern Germany and called the Ries. It is just over 20kms in diameter and was therefore produced by a 1km sized fragment. The force involved here was enough to throw melted rocks 500 kms away. This means debris was raining down on Britain 14.7×10^6 years ago. The Ries is well worth a visit. Nestling just in the middle of the crater is the tiny mediaeval walled City of Nordlingen, the city limits are almost exactly this size of the meteorite which did the damage. The city is built out of the special kind of rock, which was produced in impact, a

material called Suevite. Apollo astronauts came to Nordlingen to train and examine features they might encounter on the Moon.

Although the shock of Ries would have completely devastated Europe, it is still only a tiddler as far as impacts go. Going further a field to Canada we can locate many larger craters. One Manicouagan is now a flooded lake 100kms across. The energy needed to make Manicouagan is equivalent to all the energy produced by man since the industrial revolution plus all the force released by volcanoes and Earthquakes over the same period! This brings us to an important realisation, the devastation caused by what we call natural disaster, a volcanic eruption etc. is minuscule by comparison with processes of an astronomical provenance. Nor does it stop there; there are even larger craters around. Journey to the Moon and to the Orientale basin; this blemish on its face was caused by the equivalent of the integrated effect of five years radiation from the sun. It was all focused at one spot for a moment in time with horrific consequences.

Of course then people are correct to worry about the possibilities of being hit by things from space. Not, the little bits of rock we observe to fall about eight to ten times a year or pick up for research purposes from hot and cold deserts, but somewhat bigger things. Nobody is known to have been killed by one of the tiny events although the ploughman who witnessed the first recorded British meteorite to fall, narrowly missed being mutilated by 56lbs of rock which landed only nine yards away. Astronomical observation has already located hundreds of asteroids in an Earth crossing orbit; there are grounds for believing 1500 of 1km in size. One of these recently passed within 700,000km of the Earth; that might not sound much, but at the velocity involved, that's only 6 hours. It has been calculated there this is a 1 in 10,000 chance that a 2km diameter bollide will hit the Earth within the next century. The same researchers, Chapman and Morrison, estimate that, the fatalities of an asteroid collision would be so immense, even though impact are infrequent, the chances of dying in an impact holocaust are about the same as being killed in an air crash!

Still one should look on the bright side, life expectancy could be much worse. Everything considered so far was more or less certainly the result of an asteroid with an orbit which is inside that of Jupiter. There are lots of comets, probably about 10^{14} to be exact, which originate in the outer reaches of the solar system. Jupiter has a diameter 300 times that of the Earth and a consequential proportionally larger gravity pull. Jupiter is standing guard in the solar system protecting Earth from destruction. Occasionally of course things go a bit awry and comets that ought not to have come anywhere near Earth get diverted into its path. One such example would be one of our best known companions: Comet Encke has a period of only just over three years and has regularly been observed since it was discovered in 1819. There is

nothing in older records to support that Encke was seen before it was realised that it was a count. Apparently it was it suddenly diverted our way by an encounter with Jupiter.

We certainly have not always managed to avoid comets. In 1908, in the wastes of Siberia, at Tunguska something exploded in the atmosphere. Just about every tree in an area of ca 1000km^2 was knocked over. There is no tangible evidence on the ground of a crater and therefore the accepted explanation is that a fragment of a comet nucleus blew up in the upper atmosphere.

After Barringer's pioneering efforts, ways and means of petrologically identifying impact craters were established. High pressure minerals such as coesite and stishovite (forms of quartz) and shock features called shatter cones were to be the indicators used. But these are not perfect because like the structure of the crater itself on Earth they erode away. Nevertheless, about 150 impact craters have been recognised. The first thing which can be seen from a list is that they are not randomly distributed around the globe. They are only found in parts where the crust has been stable for long periods of geologic time - areas like the Canadian Shield, Fennoscandia, Siberia, Australia etc. The numbers are being added to at about the rate of five a year. And although they are small it is obvious that they are larger in number than can be explained the Earth crossing asteroids, so some comets are getting through. There is a way of telling just what kind of object makes a particular crater by measuring the trace element composition of the impact produced rocks and calculating the pattern of elements which have been added (more about this in next lecture). Thus it can be decided whether an iron meteorite like at the Barringer crater or perhaps a chondritic stone was responsible. The Ries Crater, unusually, might have been the result of a kind collision with a sample called an aubrite, which are comparatively rare in meteorite collections.

But the trace element signatures can also vanish, what is needed is something which can survive anything that Earth's environment has to offer. Fortunately, there is an appropriate mineral diamond. This does not necessarily mean diamond that existed in the meteorite before the impact although as was described in an earlier lecture meteorites are prolific sources of diamond. It seems that diamond is also a feature of the impact phenomenon. Below is a list of all the craters where diamond has been found.

CRATER	**Size (km)**	**Age (Ma)**
Popigai (Russia)	100	35
Ries (Germany)	24	15
Chicxulub (Mexic0o)	170, 300*	65
Puchezh-Katunki (Russia)	80	220

Zapadnaya (Ukraine)	4	115
Kara (Russia)	65	73
Obolon (Ukraine)	15	215
Illyinets (Ukraine)	4.5	395
Terny (Ukraine)	12	280
Sudbury (Canada)	300	1850

Because of the tell tale effect, it may be possible to identify the World's biggest meteorite crater. In the 19th century, just as the diamond rushes of South Africa were beginning a strange form of microcrystalline diamond called carbonado was found in Brazil; later the same kind of material was located in Central Africa. Because of the economic possibilities searches were made for the location of a Kimberlite or Lamproite pipe but none could be found to sink a mine. In any case such diamond has never been encountered in a pipe. About 1985, two British Geologist's, Dawson and Smith, one expert on Mantle rocks and the other on extraterrestrial samples suggested the strange diamond might be of meteorite origin. In the last year or two we have carried out a very careful study of the specimens from the two sources separated by the Atlantic ocean. Low and behold they match exactly in carbon isotopic composition, nitrogen abundance and nitrogen isotopes, content and the pattern of noble gases etc. The two of the samples must be related - how could this be so? There is a very simple way. Africa and South America were joined before plate tectonics decided to split them apart. A single impact could have occurred before it happened.

Quite by coincidence, just at about the time that we were coming to our conclusions, we heard about some satellite studies which had recognised a huge gravity anomaly in the Central African Republic, centred on a place called Ubangui. The gravity difference could be recording a crater, now no longer visible, of immense proportions, 800km^2 across, which occurred in Precambrian times (>2x10^9 years ago). If it is true then this is the largest known crater on Earth, the side effects would have been big enough to have wiped out practically everything on the planet. So maybe the elements of life are pointing out a situation which might well have caused the death of almost every living thing.

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