Studying planetary impacts

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The speaker did her PhD on impacts related to the Stardust mission then went to California for a few years before returning to the University of Kent for a post-doctoral then working at the Natural History Museum and is now back at the University of Kent. She explained that she would give an introduction to impact cratering, look at impact craters, explain why we study impacts and finally describe methods of investigation, including some examples of current impact research at the University of Kent using the light gas gun facility.

Introduction

The planets of the solar system formed from accretion of materials orbiting the sun 4.5 billion years ago but they are not the only bodies in the solar system; there are also asteroids and comets.

Asteroids are rocky planetisimals up to 1,000km in diameter and most are in the asteroid belt between Mars and Jupiter. They can be perturbed on to inner solar system-crossing orbits.

Comets are mainly icy bodies 1-15km in diameter, generally dormant in orbits beyond Neptune – the Kuiper Belt or the Oort Cloud. They can be perturbed on to inner solar system-crossing orbits, where ices sublimate to form cometary tails.

Bodies on orbits that cross the inner solar system can result in earth impacts but the probability is extremely low. There is a higher probability of impacts from the more common fragments after the body is fragmented, eg Comet Shoemaker-Levy (impacted on Jupiter in 21 fragments.

Impact craters on earth

In 2013, the Chelyabinsk meteor was originally an object about 20m across, which exploded in the atmosphere above Russia. The main mass of 654kg impacted on a lake, causing a 6m-wide hole in the lake and was recovered from the lake bed.

Velocities of earth impacts range from a few to tens of km/sec, with asteroids typically at 16km/sec and comets up to 72km/sec. Impacts cause extreme changes in pressure (in GPa) and temperature (thousands of degrees). Impacts are identified by their morphology, causing circular features, sometimes with a rim and gravitational anomalies. Small, simple, bowl craters show low gravity due to low-density impact breccias on the crater floor, while larger complex craters with uplifts can show positive anomalies due to bringing up more dense material from depth. Also diagnostic is the presence of impactites of 3 types – shatter cones, suevite (a mix of molten and brecciated terrestrial rock) and tektites (impact glass). All are composed of the country rock. Impact fragments (meteorites) may also be present along with high pressure and high temperature polymorphs.

There are 190 confirmed impact craters on Earth, including:

- Manicouagan Crater, Quebec, Canada, >200Ma and c.100km diameter, caused by a 5km diameter impactor; it can be linked to the Bristol impact layer;
- Shoemaker Crater, Australia, c1.7Ga and about 30km diameter;
- Gosses Buff, Australia, c140Ma and originally c22km diameter with the remaining raised feature being about 5km diameter;
- Vredefort Crater, South Africa, >2Ga and originally c300km diameter being caused by a 10km diameter impactor; and
- Barringer Crater, Arizona, USA, 50,000 years old and 1,200m diameter caused by a 50m diameter impactor and associated with the Canyon Diablo meteorites, with the largest fragement being the Holsinger meteorite.

Why do we study impacts?

Planetary impacts have been occurring since the beginning of the Solar System (and still occur). This is a universal process in all bodies in the Solar System:

- The moon has over 1,000 craters, with the south polar Aitkin Basin at c2,500km diameter;
- Mercury has the Coloris Basin at 1,500km diameter;
- Venus is covered in cloud but radar images show craters, eg the Mead Crater, c280km diameter, but none are smaller than 3km diameter because the thickness of the atmosphere causes smaller objects to break up;
- Mars has the Hellas Basin at c2,300km diameter and we are now seeing really fresh craters, one example being 30m across with ejecta thrown out to 15km. The moons of Mars, Phobos and Deimos, also have craters;
- Callisto, a moon of Jupiter, has the Calhalla Crater with a bright central ring 360km in diameter surrounded by a darker ring 1,900km in diameter;
- Titan, a moon of Saturn does not have many craters because of its active surface;
- Pluto and Charon have halo craters of bright water ice with dark methane ice rims;
- Asteroids are covered in craters; and
- Comets have features, which are thought to be impact craters.

The study of impact craters is important because their morphology tells us about the surfaces involved, they may excavate underlying materials, they indicate the degree of activity of the body and allow dating. Impacts could have played a major role in the evolution of life because they sterilise the surface, increase dust in the atmosphere leading to cooling, can increase sulphur and carbon dioxide leading to acid rain and they ignite wildfires and induce tsunamis if they fall in the ocean. In particular, the contribution to the Cretaceous – Tertiary extinction event due to an impact in the Chixculub Crater in Yucatan, which caused >1,000 times more iridium at the boundary than in the upper and lower layers, has been recognised. However, their effect is not just destructive in that they enable other species to develop, they deliver and potentially created materials vital to life and they produce habitats conducive to the development of life.

Impacts occur at all scales, not just very large. For example, one of the Apollo missions brought back a 0.1mm grain of moon dust, which on examination was found to have an impact crater on its surface. Dusty impacts have been recognised as a potential hazard, eg in requiring replacement of solar cells for the Hubble Space Telescope. Instruments have been installed to sample dust via impacts as in the long-duration exposure facility, the Stardust mission to collect dust from a comet's tail and the cosmic dust analyser on Project Cassini.

Methods of studying impacts

There are 3 methods of studying impacts, field study, computer simulation using hydrocodes and laboratory experiments. Only remote field study is possible on other planets and we do not know the details of the impactor or country rock, unless we find remains. It is best to observe them as they occur. Models need validation by laboratory experiments.

At the University of Kent, the light gas gun facility can shoot at velocities of 1-8cm/sec using buckshot at 100-300μm or grains at 300μm-3mm with a maximum target size of 100x100x100mm solids. All laboratory experiments are limited in size. The sites of nuclear test carried out before the Nuclear Test Ban Treaty the last century also somewhat simulate the shocks generated by impacts.

Examples at Kent University include forming impacts relevant to the Stardust mission. We need to determine impact alteration to determine the original mineralogy and experiments involve looking at the effects of size, shape and impact angles. It has been suggested that methane production on Mars is possibly replenished by impacts affecting olivine basalts but this has not been confirmed. Organic synthesis by impacts may also be possible to produce amino acids. Videos of impacts are used to study secondary ejecta patterns.