Impact Cratering in the Solar System

Overview

This activity introduces students to the process of impact cratering and its importance in early solar system processes, and how we can use an understanding of impact craters to tell us about the surface processes of planetary bodies. This activity combines a hands-on experiment with satellite imagery from across the Solar System, allowing students to interpret planetary surfaces based on their experimental models.

Level

This activity supported by the listed extensions is suitable for secondary-school classes but can be modified for all ages.

Subject

The basic cratering experiment demonstrates the mechanics of impacts and crater formation, and gets students to apply the scientific method to setting up and carrying out an experiment.

The extensions to this activity demonstrate the interdisciplinary nature of planetary science, and links physics to chemistry and biology.

Timeline

Total activity takes approximately 1 hour, with extensions adding extra time.

Background

Bolide impacts were an important process in the early chaotic Solar System, and continue to control the topography of many terrestrial bodies in our celestial neighborhood. Studying impact craters can allow us to find out about the ages of planets or moons, to investigate the material below the surface of a planet, and to discover whether a planetary surface has been volcanically active or not. Impact craters are formed by collision with bolides, such as meteorites. Further background information can be found here - https://www.lpi.usra.edu/education/explore/shaping_the_planets/impact-cratering/ - and here - https://www.psi.edu/epo/explorecraters/background.htm - and can be tailored to different age groups.

The basic experiment is described below, followed by extensions to the activity under the heading "Applying these results".

Notes

This experiment can be a little bit messy - for younger classes, a demo set-up with student volunteers coming up to drop "meteorites" to form craters might work better than having trays for each group.
Large bin liners cut into a single sheet make a great floor covering to set up on if newspaper isn't available.
Pushing back desks and setting up the experiment on the floor is a good way of keeping everything tidy and reducing spills!

Materials

- 1 basin per group - disposable roasting tins work well for this
- Bags of flour - you need enough flour to fill each tray to approx. 5 cm depth; 1 1kg bag of flour will work for 6 - 8 trays (depending on tray size)
- Cocoa powder - 1 tub will work for the full class as each group just needs a sprinkle between experiments
- Rulers and metre stick: 1 ruler per group to measure resulting impact craters, plus a metre stick to share between groups to measure drop height
- "Meteorites" - each group should have one or two marbles to act as impactosrs, plus then have some extra different-sized impactors to share around (golf balls or large marbles work well)
- 1 sieve - this is to sprinkle on the cocoa powder evenly when setting up the experiment, only one needed for the class
- Newspaper or plastic sheets to keep the classroom tidy
- Results table - this can be printed out for students, or students can design their own based on the hypothesis they want to test

Setting up the experiment

We're going to set up an experiment to investigate impact cratering. We will create a "planetary surface" using a basin of flour, and will make the subsurface a different kind of rock by sprinkling a thin layer of cocoa powder over the top: this will let us see how impact craters affect the layers of rock beneath the surface. We will use marbles and golf balls to represent different size impactors, and drop them from different heights into the flour.

When carrying out an experiment, it's useful to make some predictions which we can test. Think about the following questions and write down some predictions:

- What do you think will happen if you drop the marbles from different heights?
- What do you think will happen if you drop different sized marbles?

- What do you think will happen if you drop a marble straight down and then gently throw the marble at a slight angle?

- What happens if you drop marbles over previous craters?

How can you test these predictions?

You'll want to record the **crater morphology** when you carry out this experiment: you can do this by sketching the crater shape, measuring the diameter of the crater, and measuring how far the crater ejecta gets sprayed out from the crater - these are called ejecta rays (Figure 1 in this article shows craters with these rays: https://physics.aps.org/articles/v11/64).

You can "reset" the experiment by levelling out the flour and applying more cocoa powder.

Method

1. Fill the basin with flour to approximately 5 cm depth
2. Level off the flour without compacting it by tapping the sides of the basin
3. Sprinkle some cocoa powder over the top using a sieve
4. Drop marbles from a range of heights (measure the height using the metre stick) and record the results (see results table)
5. Carefully pick out the marbles from inside the impact craters without disturbing the flour (if possible) and measure the diameter of the crater and the length of any **ejecta rays**

Results and Discussion

Did you produce ejecta rays of white flour around your craters? What does this tell you? What conditions led to the largest crater diameters and ejecta rays? Why?

Applying these results

Now you have some experimental results - but what can these tell us about planetary-scale impacts across the Solar System?

Overlapping and "complex" craters

Sketch the result of dropping impactors in the same region, so that their craters and ejecta overlap. Can you tell which is the oldest based on how they overlap? Compare your sketch

to this planetary impact crater on Vesta:
https://solarsystem.nasa.gov/resources/1926/successive-formation-of-impact-craters/

Look at the different **crater morphologies** described here:
https://www.lpi.usra.edu/education/explore/shaping_the_planets/impact-cratering/. Why might you not be able to see any “complex craters” in your flour experiment?

Now look at some more satellite images of craters on planetary bodies and apply what you have learned: you could print out this image of Mercury - https://solarsystem.nasa.gov/resources/2266/mercurys-caloris-basin/ - and label simple and complex crater, craters that look older and eroded or younger and more distinct. Find areas where craters overlap and try to figure out their relative ages. This is how planetary scientists use satellite imagery of impacted terrains to piece together the planet’s geological and impact history.

Crater counting

As well as overlapping each other, craters can overlap other features and this can tell us about the order that geological processes happened on the surface of planets. **Crater counting**, where planetary scientists count and characterise the impact craters on a surface, is a key way to figure out the relative ages of different planetary surfaces. Heavily cratered surfaces are older, while smooth surfaces are younger.

We can try to model this with our flour basins: “reset” the experiment, then heavily crater the surface - repeatedly drop marbles to create a surface with lots of craters, some overlapping. Now, using the sieve and some more flour or cocoa powder, cover half the tray in a light new layer of powder. This represents a thin lava flow erupted from a volcano on your planet, that covers the old, cratered surface. Describe what this new “younger” surface looks like - can you see traces of the old impact craters through the new layer of powder? Now, drop some impacts randomly in the basin - some on the new surface, some on the old. Can you still tell apart the new surface? Have a look at this detailed satellite image of an area on Mercury and try to label some smoother, “fresh” surfaces and some older, heavily-impacted areas: https://solarsystem.nasa.gov/resources/2266/mercurys-caloris-basin/ .

Astrobiology, ejecta rays and subsurface geology

One thing you’ll have noticed is that the white flour under the surface get **excavated** and brought to the surface and sprayed out over the cocoa powder in **ejecta rays**. This is interesting and useful - it means that **subsurface material** - here, the flour - gets brought up to the surface. On our flour and cocoa powder planet, if a **satellite** was orbiting and taking pictures of the surface, without impact craters the planet would just look like it was made of cocoa powder, and we wouldn’t realise there was flour underneath. This is true for planets made of rock as well as those made of baking ingredients - impact craters can reveal the rocks beneath the surface.

Compare the ejecta rays formed with the flour and cocoa powder to these ejecta rays on planetary bodies:

https://solarsystem.nasa.gov/resources/2268/fresh-impact-on-mars/
https://solarsystem.nasa.gov/resources/108/pwyll-crater-on-europa/

When it comes to searching for traces of **astrobiology**, planetary scientists often focus on the subsurface: **biosignatures** may be preserved below the surface, from microbes or other simple organisms. Impact craters offer a way to sample the material below the surface of the planet, without the expense and complication of sending drilling devices to other planets: https://www.bas.ac.uk/data/our-data/publication/impact-excavation-and-the-search-for-subsurface-life-on-mars/

Kinetics of impacts

The lesson can be extended with a physics and mechanics focus, by looking more in depth at the kinetics of impact cratering. Some useful resources for this are listed below. A starting point for this discussion is interrogating the difference in crater size dependent on the height that the “meteorite” is dropped from. In planetary impacts, impactors are not dropped onto the surface: they collide at high velocities. What does dropping the sample from a greater height change when it comes to the kinetics of impact? What is this analogous to in an actual planetary impact?

https://www.lpi.usra.edu/exploration/education/hsResearch/crateringLab/lab/part1/background/
https://www.lpi.usra.edu/exploration/education/hsResearch/crateringLab/lab/part2/background/

Citizen science projects

Apply your knowledge to some real-life satellite images to help categorise craters on Mars and Earth.

Try out the tutorial here and identify some craters on Mars: https://craters.planetfour.org/
Look out for some Earth-based impact craters - https://www.lpi.usra.edu/planetary_news/2020/04/30/join-the-vigie-cratere-citizen-science-project-and-become-a-crater-hunter/ (requires registration)