Meteorite crater simulation by controlled explosions: a more realistic model

Authors: Juan Antonio Prieto Sánchez (teacher)
Sergio Ramos Guerrero
Juan José García Delgado
Debla Blanco Andrades

Abstract

There are two different types of craters that can be found in nature: volcanic craters and impact craters produced by the impact of asteroids on the surface of a celestial body.
These latter give conclusive positive data favouring the formation of celestial bodies by acretion of smaller ones, in addition they give data on the frequency of impacts and the approximate planetary age.
An experimental pattern allowed for the study of these natural phenomena.
We have learnt that simulating the formation of meteorite craters by impacting free falling objects or by objects that have been thrown by mechanical means give similar results to the real phenomena.
The impact of a meteorite on a planetary surface occurs at a very high speed and releases a high amount of energy. Therefore, we recreated this release of energy by using controlled pyrotechnic objects[1].

1. Volcanic craters vs meteorite craters

A crater is defined as a cavity or depression caused by an explosion either from a volcanic eruption (volcanic craters) or from a meteorite impact.

A volcanic crater is a depression located at the top of a volcano in which a vent occurs. They can be formed either by an explosion or by subsidence (caldera).
During volcanic eruptions, a great pressure is built up inside the volcano due to volcanic gases and molten magma. This pressure leads gases and magma to rise from the magma chamber reaching the craters vent. The lava temperature, its composition and viscosity will determine how violent the eruption will be.
A meteorite crater is the depression that the collision of a meteorite produces on the surface of a celestial body. Meteorites can be extremely small such a grain of sand, or can measure several kilometers. Their kinetic energy can be substantial and therefore, when colliding, it could be considered that the meteorite has endergone an explosion. Occasionally, if the meteorite is reasonably large the impact can reach the magma from the inside of the planet, creating a cirque.
Their strength is due to the impact speed (between 50,000Km/h and 100,000Km/h) and their mass. It is estimated that the impact of a meteorite travelling at 75,000Km/h could release sufficient energy so as to produce the biggest natural disaster seen on Earth.

The speed of a meteor will reduce on entering a planet's atmosphere due to friction.

---

[1] Astronomers have classified the celestial bodies of the universe as: stars, planets, natural satellites or moons, comets and meteors.

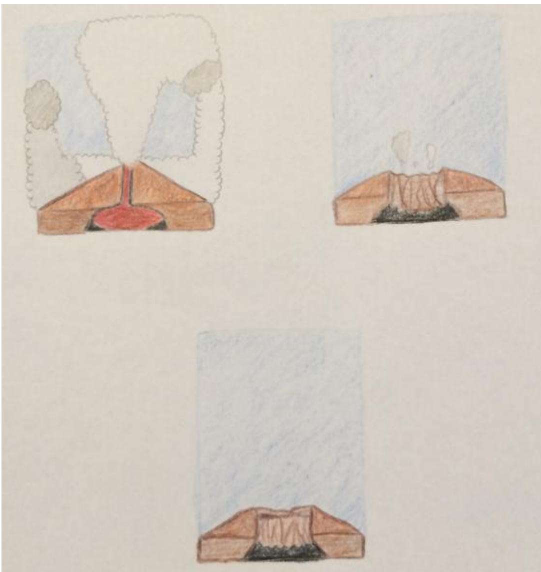
Their size and shape are also affected due to ablation of the surface. If the meteor is small (fist-sized) it vaporizes before hitting the ground. Most meteoroids disintegrate when entering the Earth's atmosphere.

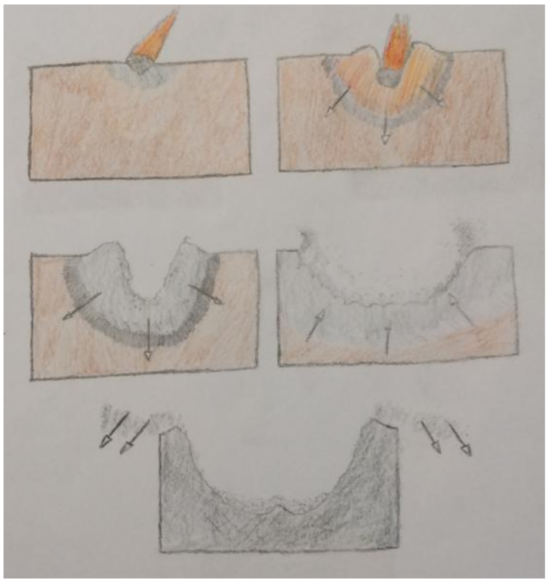
Occasionally, they suffer fragmentation during fall producing dust particles that can persist in the atmosphere for up to several months.

However, if the meteoroid is sufficiently large it survives to impact on the ground, although it will have been reduced in size during entry into the atmosphere.

Craters formed by meteorite impacts will contain meteorite debris around them and will weather through time becoming less visible.

The following photographs show the differences between volcanic and meteorite craters.





Figures 1-2.- Natural formation of volcanic and meteorite craters

2. Information contained in meteorite craters

A meteorite is a solid piece of a celestial body such as a comet, asteroid, or meteoroid. They originate from outer space and survive their crossing through the atmosphere impacting with the surface of a planet.

The majority of meteorites come from the Asteroid belt or are part of the Trojan asteroids, a large group of asteroids close to Jupiter. The change in their orbit can be provoked by collisions and they can be orbiting around the solar system for thousands or even millions of years before falling onto a planet.

Planet Earth and other rocky bodies in the solar system show much evidence of these meteorite impacts. Impact craters of different ages and sizes can be also found, for instance, on the surface of Mercury, Mars and the Moon. They constitute a fundamental geological process in our Solar System. On Earth, they have played an important role in evolution either by creating habitats or by causing the extinction of some life forms.

Craters formed by a meteorite will vary according to the speed, mass and size of the meteorite. Similarly, the trajectory is also very important in crater formation.

Meteorite impact craters are an excellent source of information because:

- The number of impact craters on the surface of a planet is related to the age of that planet.
- The crater inclination shows the provenance of the meteorite. The calculation of the inclination can be done in two different ways:
    - Before impact with the help of photographs taken from different angles[2]. Its velocity can be calculated through the light trail images captured by the photographs. Likewise, its trajectory can be calculated in order for it to be retrieved.
    - In the crater after impact. When the angular inclination of the trajectory is sufficiently acute the crater will show asymmetries.

A major problem in relation to the interpretation of craters is that the impact conditions are unknown. It is not easy to determine the mass, size, speed and trajectory inclination of a meteorite from the characteristics of the crater formed.

However, it has been observed that some craters share a similar structure. The upper layer is weaker than its lower layers which are more rigid. The impact perforates the top layer and creates two concentric craters. The ejected materials show a pattern in which the materials produced by the top layer are situated separately from those coming from the lower layers. This different position within the main crater is very helpful in order to calculate the direction and the angle of the impact.

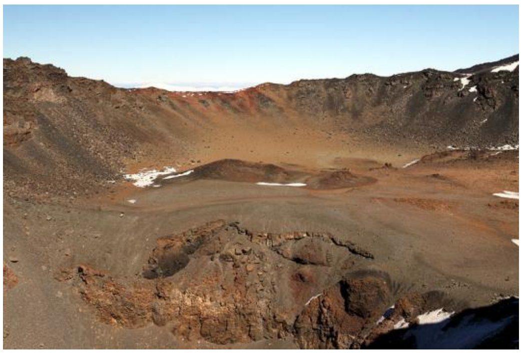
3. Simulations: a more realistic model

For the experimental part of the study we built a “cratometer”. It consists of a box filled with beach sand that has been covered with cement powder.

3.1. First simulation: a volcanic crater

Our first experiment was to simulate the formation of a volcanic crater. In order to do so we inserted an L-shaped straw at 10cm from the surface of our “cratometer”. We then blew profusely to produce a crater from the impact of the air.

[2] In 1964, a world net of cameras was installed as to film the night sky.

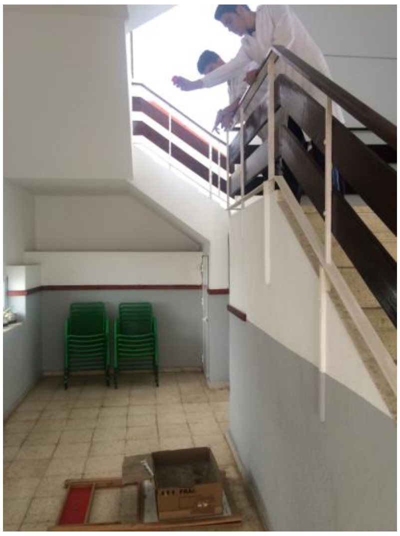
Figures 3-4.- Our crater and a real volcanic crater: crater Pico Viejo in Tenerife

3.2. Second simulation: Meteorite craters formed by free falling objects

Before starting the simulation we searched the web to get information on similar experiments. Particularly interesting we found some astronomy blogs such as “Ordenes” in 2007, science experiments performed by high school students during their science fair such the ones from Colegio Europa in 2008 or the experiments presented by Ordoño and Tadeo in 2010 at the Bezmiliana science club.
Our first intention was to follow their procedures creating craters by free falling objects or by launching objects with a catapult. We decided to study the impact produced when objects with different mass fall from the same height.

Figures 5-6.- Cratometer and some spheres used in the experiment

Figures 7-8-9.- The making of the experiment

The speed of the impact can be calculated by the Principle of conservation of mechanical energy if friction is not considered.

$$E_{Mo}=E_{Mf}$$

$$E_{co}+E_{po}=E_{cf}+E_{pf}$$

$$mgh_o=\frac{1}{2}mv_f^2$$

$$v_f=\sqrt{2gh_o}$$

Table 1-Impact results

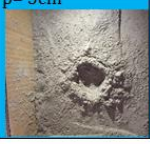
Objetos / Alturas	**1 bola** m=30.4g d= 1.8 cm 	**2 bola** m= 68. 1g d= 2.5cm 	**3 bola** m=261.5g d= 4cm 	**4 bola** m= 115g d= 5cm 
2 m	v= 22.53 km/h a= 2cm p= 2.5cm 	v= 22.53 km/h a= 7x5cm p= 3cm 	v= 22.53 km/h a= 5cm p= 4cm 	v= 22.53 km/h a= 8cm p= 4.5cm 
2.85 m	v= 26.91 km/h a= 2cm p= 2.5cm 	v= 26.91 km/h a= 7x9cm p= 3cm 	v= 26.91 km/h a= 8x9.5cm p= 4cm 	v= 26.91 km/h a=7.5x8.5cm p= 4.5cm 
8.10 m	v= 45.38 km/h a= 6cm p= 3cm 	v= 45.38 km/h a= 9x8cm p= 5cm 	v= 45.38 km/h a= 11cm p= 7cm 	v= 45.38 km/h a= 7cm p= 4cm 

Table key
a:crater width
p:crater depth
v: impact speed
m: mass of the object
d: diameter of the object

Conclusions:

- The best results were obtained by smaller objects falling from greater heights.
- Larger objects and their craters had the same shape.
- According to Emstson and Claudin (2015) the data obtained in these simulations is not totally reliable due to the impact velocity:

"Impact structures are formed by a cosmic body travelling at a velocity exceeding that of sound commonly around 5 km/s impacting target rocks leading to the sudden intense spreading of shock waves. These conditions only occur with larger projectiles (a few hundred tons and more) that are not significantly slowed down by friction in the atmosphere that impact the ground at cosmic velocities (10 – 70 km/s)".

In their study both authors also explain that:
"The excavation in impact cratering is inextricably linked with the propagation of shock waves. Spreading outwards from the point of contact, compressive shock waves are permanently reflected from the free target surface as tensile rarefaction waves of comparable intensities and, like the shock waves, are propagated downwards. In this way, all rock particles behind the expanding shock front are "captured" by both the compressive shock and the tensile rarefaction, and both combine into a vector of acceleration".

Finally they state that:
"The excavation stage ends on release from shock and when the displacements by excavation cavity formation and downwards/sideward compression reach an end. The now existing bowl-shaped structure surrounded by an uplifted rim and a blanket of ejected material is termed the transient crater obviously indicating a continuation of the impact cratering process arriving in the modification stage".

These modification stages are not covered in our study.

3.3. Third simulation: Meteorite craters formed by controlled pyrotechnical explosions

During the second stage of our research we found it impossible to carry out our simulations at greater heights or at higher speed. Therefore, we thought it necessary, in order to make our simulation more realistic, to use devices that could liberate more energy.

Pyrotechnical explosions liberate large amounts of energy. This energy can be approximated to the energy released in meteorite impacts. For that reason we decided to work with controlled explosions.

Figure 10-11.-Crater formation by controlled explosions

Once more, through the Principle of the conservation of energy, the energy released in the explosion, E_Q, can be related to the kinetic energy, E_C, and subsequently the speed at the moment of impact can be calculated.

$$E_Q = E_c$$

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

$$v = \sqrt{\frac{2E_Q}{m}}$$

A class III pyrotechnical device contains 2,7 grams of gunpowder. This is the largest amount of gunpowder that can be bought by the public in a firework within the Spanish legislation. According to Zimbelman (2014) the energy liberated by this amount of powder is 30 J. Using the previous equation the speed can be calculated as 149.07m/s or 0.149Km/s. This is ten times faster than any of the objects falling from the highest altitude in the previous experiment.

Figure 13. Controlled explosive

Our cretar compared with a real crater, Giordano Bruno (crater on the moon, NASA):

4. Bibliographic references

- Volcanic craters vs meteorite craters

https://es.wikipedia.org/wiki/Cr%C3%A1ter_de_impacto

Information contained in meteorite craters
http://www.scielo.org.bo/scielo.php?script=sci_arttext&pid=S1562-38232008000100007

http://meteoritoscanarias.blogspot.com.es/p/crateres-de-impacto.html

http://www.cab.inta.es/es/noticias/92/la-forma-de-los-crateres-proporciona-pistas-acerca-de-la-direccion-de-los-impactos-de-asteroides

GIBILISCO, S. (1991). Cometas, meteoros y asteroides: cómo afectan a la Tierra. Madrid: McGraw-Hill.

- Simulations: a more realistic model

  - First simulation: a volcanic crater

https://es.wikipedia.org/wiki/Pico_Viejo

  - Second simulation: Meteorite craters formed by free falling objects

http://estructuras-de-impacto.impact-structures.com/?page_id=2551

  - Third simulation: Meteorite craters formed by controlled pyrotechnical explosions

http://todopetardos.com/noticias/que-petardo-es-el-mas-fuerte-35/

http://www.si.edu/content/consortia/zimbelman_presentation.pdf

https://en.wikipedia.org/wiki/Explosion_crater