ISSN 0326-1778 (Impresa)
ISSN 1853-6581 (En Línea)

HISTORIA NATURAL

Tercera Serie | Volumen 9 (1) | 2019/5-15

A VERY UNUSUAL CLUSTER OF MULTIPLE SMALL IMPACT CRATERS PROBABLY CREATED BY THE IMPACT OF A SPLIT COMETARY NUCLEUS IN PATAGONIA

Bajada del Diablo craters field, Chubut, Argentina: the impact of a small split comet?

Maximiliano C. L. Rocca[1] and Rogelio Daniel Acevedo[2,3]

[1]The Planetary Society. Mendoza 2779, 16A (1428DKU) Ciudad de Buenos Aires, Argentina.
maxrocca2010@gmail.com
[2]CADIC-CONICET, Houssay 200 (V9410CAB) Ushuaia, Tierra del Fuego, Argentina.
[3]University of Tierra del Fuego, ICPA, Walanika 250 (V9410BWD) Ushuaia, Tierra del Fuego, Argentina.

AZARA
FUNDACIÓN DE HISTORIA NATURAL

umai Universidad Maimónides

Abstract. An analysis of the impact event that created the Bajada del Diablo (S 42º 45′, W 67º 30′) impact crater strewn field is presented. At mid Pleistocene (780,000 to 130,000 years ago), about 550 impact craters of less than 400 meters in diameter were created simultaneously in an area of about 480 square kilometres at Bajada del Diablo in central Patagonia. Absence in the maps of craters of a clear dispersion ellipsoid in the area points toward the idea of the impact of a very fragmented small cosmic object. Cosmic impactor could have been: 1) a "rubble pile" type Near Earth Asteroid or 2) a small split cometary nucleus. The absence of meteorites in the area is in conflict with the hypothesis of the impact of a rocky Near Earth Asteroid. More probably, an ice comet nucleus was the responsible of the impact since the impact of such an icy object would not have left visible traces of itself after more than 130,000 years. After some analysis the impact of a small 200 meters wide split ice comet nucleus is presented as the most probable scenario.

Key words. Bajada del Diablo impact crater field, cometary nuclei, impacts in South America.

Resumen. Se hace aquí un análisis detallado del evento de impacto cósmico de Bajada del Diablo (S 42º 45′, W 67º 30′). El evento ocurrió probablemente en el Pleistoceno Medio (780.000 a 130.000 años atrás), y originalmente unos 550 cráteres de impacto de menos de 400 metros de diámetro fueron creados simultáneamente en unárea de 480 kilómetros cuadrados en Bajada del Diablo, Chubut, Patagonia central. Hoy solo sobreviven a los procesos erosivos que han actuado desde el evento de impacto unos 200 cráteres de impacto. La ausencia de una clara elipse de impacto en la distribución de planta de los cráteres de impacto evidencia el impacto de un objeto que ya venía muy fragmentado antes de entrar en la atmósfera terrestre. La ausencia en el sitio mismo de fragmentos de meteoritos (tanto pétreos como metálicos) apunta a que el objeto que impacto estaba principalmente compuesto por hielos, y probablemente era un núcleo helado de cometa fragmentado. Luego de un análisis lógico se favorece el origen de estos cráteres de impacto a partir del choque de un núcleo de un cometa de aproximadamente 200 metros de diámetro.

Palabras clave. Campo de cráteres de impacto de Bajada del Diablo, núcleos de cometas, cráteres de impactos en Sudamérica.

INTRODUCTION

A very remarkable site of a very large meteorite impact craters field is present in this area. The impact craters were discovered in the 80's (Corbella, 1987). Approximately 200 small simple-type craters are widespread over an area of 35.2 x 17.6 kilometers, that is 480 square kilometers in Patagonia (Rocca, 2006; Acevedo *et al.*, 2007; Ponce *et al.*, 2008; Acevedo *et al.*, 2009; Acevedo *et al.*, 2010; Acevedo *et al.*, 2011; Acevedo *et al.*, 2012).

From the published information here are the numbers of a census of 119 Bajada del Diablo's impact craters according to their size:

Table 1 - Census of impact craters of Bajada del Diablo. Source: Acevedo *et al*. 2009; 2012.

Diameter (in meters)	Quantity of catalogued impact craters
400-350	9
350-300	6
300-250	19
250-200	31
200-150	27
150-100	22
Less than 100	5

Most of these craters show clear evidences of having raised rims. Craters are mainly located on areas were fluvial sedimentary deposits (sandstones and conglomerates) of Pliocene-Early Pleistocene age are exposed but, many craters are also located on several different geologic terrains like, e.g., small Miocene volcanic basaltic plateau and piroclastic rocks. Areas exposing Pleistocene and Recent fluvial sediments show no crater so the impact event was not very recent.

Because neighboring or double craters never overlap each other can be interpreted that all structures were formed simultaneously during one single massive impact event.

Ejecta blankets associated to the craters of Bajada del Diablo are mainly developed on the NE side of each impact crater so it is clear that the cosmic objects came from the SW (Figure 1).

In situ detailed geophysical research has showed significant gravimetric and magnetic anomalies associated to the largest craters. This is a good non geomorphologic confirmation of the impact origin of these depressions (Prezzi *et al.*, 2016).

Figure 1 - Map of the Chubut Province, Patagonia, Argentina, showing the location of the Bajadadel Diablo craters field.

Laboratory tests of rock samples have showed nickel'srich anomalies, and Lawren cite bearing melt micro spherules associated to the ejecta blankets of some craters, but so far no meteorite specimens associated to the craters have been found.

Metallic and vitreous microspherules have been discovered into animpacted limestone of tuffaceous material that is located immediately underneatheolian sediments at the center of the "crater 8", (Acevedo *et al.*, 2009; 2012)

Age of this impact event has been estimated by the local geologic characteristics of the site as between 130,000 and 780,000 years ago, that is at mid Pleistocene times (Acevedo *et al.*, 2009; Acevedo *et al.*, 2010; Acevedo *et al.*, 2011; Acevedo *et al.*, 2012**).**

No doubt, many craters have been erased by the Quaternary to Recent fluvial erosion processes and what we see today (about 200 craters) is just a fraction of the original population of craters. By the careful study of satellite images and aerial photos of the area, the original total number of impact craters has been estimated in about 550 (Acevedo *et al.*, 2009; 2012). It has been also estimated that, since the impact event at the mid Pleistocene times, only about one third of the original population of craters have survived the subsequent erosive processes.

No dispersion ellipse

When meteorite showers reach the ground they distribute themselves into a strewn field which usually defines an elliptical shaped area called, the dispersion ellipse (Krinov, 1966). The long axis is coincident with the direction of motion of the swarm and the most massive fragments normally fall at the far end of

Figure 2 - Close up satellite real color image of the Filu-Co Plateau in Bajadadel Diablo area, Central Chubut, Patagonia, Argentina. Many small impact craters are clearly showed. Largest impact crater showed in the image has 400 meters in diameter. Credits. NASA - LANDSAT VIEWER.

the dispersion ellipse. There is no evidence for those patterns in the case of Bajada del Diablo craters. Medium to large craters are randomly distributed all over the whole area of the craters field. No clear dispersion ellipse is visible in the panoramic satellite images and aerial photographs of the area (Acevedo *et al*., 2009; 2012; Figure 2).

Most probably, this craters field is the result of the impact of a small cosmic object (comet or asteroid) which was broken in hundreds of fragments by the Earth's gravity force short before entering into the atmosphere. Then the swarm of fragments created the crater field.

The object probably broke into fragments at or closer than the Roche's Limit (distance at which a satellite made of a conglomerate of fragments influenced by the gravitation of a central mass (e.g., a planet) can be in equilibrium. For such a satellite in orbit around a planet this critical distance at which the object's fragments will break up because of the gravity tidal forces is 2.44 times the radius of the primary. In the case of the Earth that distance is 15,550 kilometers.

It is interesting to note from the numbers in the above mentioned census that there are very few small, less than 100 meters in diameter, impact craters at Bajada del Diablo. There is a clear "cut" in the amount of craters *vs.* its diameter. This is not a consequence of the erosion, the lack of very small craters is a real fact and it is not an effect of modern or ancient local erosive processes.

Probably the smallest cosmic objects in the swarm were completely burnt and destroyed in the passage through the atmosphere before reaching the ground to open an impact crater.

On average, in an impact event, a cosmic object opens a crater 20 times the size of its diameter (French, 1998). Thus, having the present (about 200) and the total original number of impact craters created in the event of Bajada del Diablo (about 550) we can calculate an approximate value for the size of the asteroid or comet using the basic physical calculations in Melosh, 1989.

By this system we have first estimated the size of the objects that created each impact crater of the Bajada del Diablo's total original population. Then, putting all the objects together, we found that the original interplanetary object that impacted at Bajada del Diablo had a pre-atmospheric total diameter of about 200 meters.

NATURE OF THE COSMIC OBJECT IMPACTED AT BAJADA DEL DIABLO: COMET *vs.* ASTEROID

Was the object a stony/iron Near Earth Asteroid (NEAs) or an icy comet nucleus? Near Earth Asteroids (NEAs) are asteroids that orbit around the Sun in elliptical orbits and with potentially inner planets crossing trajectories, including Earth. The largest example known is 1036 Ganymed, which is a stony object 40 kilometers in diameter. It is well known that asteroids are the building block of terrestrial planets in the Solar System, with variable abundance of rock, metals and volatiles (Bottke *et al*., 2002; Norton, 2002).

Meteorites are no doubt small samples from Near Earth Asteroids. They are composed mainly of silicates (olivine and pyroxenes) and /or metallic alloys of Fe-Ni (Norton, 2002). Many NEAs are not dense solid monolithic objects. They are in fact conglomerates of rocks and metal fragments bound together by their weak gravity force. They are known as "rubble pile" type asteroids (Bottke *et al*., 2002).

In the case of many small terrestrial meteorite impacts (those of less than 1.0 kilometers in diameter) there are small meteorite specimens located at the ejecta blankets and around the impact craters that have survived the violent impact event. This is a well stated fact when the impacting object was a Near Earth Asteroid (NEA) that is a planetary object composed of silicate rocks and/or metallic Fe-Ni (Grieve 1990; Grieve 2001). The so far apparent absence of meteorite fragments at Bajada del Diablo is tentatively interpreted as evidence that the cosmic object that created the impact craters was not a "rubble pile" type NEAs.

So by logic we have only the second hypothesis: the impact of an icy small split comet nucleus. The most probable interpretation is that the cosmic impactor at Bajada del Diablo event was a comet nucleus mainly made of ices. After more than half a million years no visible fragments of the impact of a small icy comet nucleus would have left around the impact craters of Bajada del Diablo. Ices would have vanished and evaporated very soon.

A comet is an icy small Solar System body (SSSB) that, when close enough to the Sun, displays a visible coma (a thin, fuzzy, temporary atmosphere) and sometimes also a tail. These phenomena are both due to the effects of solar radiation and the solar wind upon the nucleus of the comet. Comet nuclei range from a few hundred meters to hundreds of kilometers across and are composed of loose collections of ice, dust and small rocky particles. Comets have been observed since ancient times (Wilkening, 1983; Festou *et al.*, 2004).

Comets have a wide range of orbital periods, ranging from a few years to hundreds of thousands of years. Short-period comets originate in the Kuiper belt, or its associated scattered disc which lie beyond the orbit of Neptune. Longer-period comets are thought to originate in the Oort cloud, a hypothesized spherical cloud of icy bodies in the outer Solar System. Long-period comets plunge towards the Sun from the Oort cloud because of gravitational perturbations caused by either the massive outer planets of the Solar System (Jupiter, Saturn, Uranus, and Neptune), or passing stars. Rare hyperbolic comets pass once through the inner Solar System before being thrown out into interstellar space along hyperbolic trajectories (Wilkening, 1983; Festou *et al.*, 2004).

Comets are distinguished from asteroids by the presence of a coma or a tail. However, extinct comets that have passed close to the Sun many times have lost nearly all of their volatile ices and dust and may come to resemble small asteroids. Asteroids are thought to have a different origin from comets, having formed inside the orbit of Jupiter rather than in the outer Solar System. The discovery of main-belt comets and active centaurs has blurred the distinction between asteroids and comets (Wilkening, 1983; Festou *et al.*, 2004).

Comet nuclei are known to range from about 100 meters to more than 100 kilometers across. They are composed of rock, dust, water ice, and frozen gases such as carbon monoxide, carbon dioxide, methane and ammonia. Because of their low mass, comet nuclei do not become spherical under their own gravity, and thus have irregular shapes. Their densities have been estimated from 0.2 to about 1.0 grams per cubic centimeter (Campins and Fernandez, 2002; Festou *et al.*, 2004; A'Hearn and Combi, 2007; Thomas *et al.*, 2013a and b).

They are often popularly described as "dirty snowballs." Recent observations have revealed dry dusty or rocky surfaces, suggesting that the ices are hidden beneath the crust. Comets also contain a variety of organic compounds; in addition to the gases already mentioned, these may include methanol, hydrogen cyanide, formaldehyde, ethanol and ethane, and perhaps more complex molecules such as long-chain hydrocarbons and amino acids. Surprisingly, cometary nuclei are among the least reflective objects found in the Solar System. Minor amounts of silicates grains (olivine and pyroxenes), sulphides and Fe-Ni are also present in the cometary nuclei (Zolensky *et al.*, 2006; Figure 3).

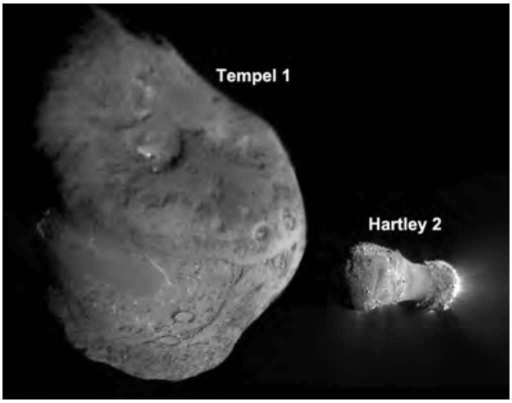

Figure 3 - Image showing the icy nuclei of the comets 9P/ Tempel 1 and 103/P Hartley 2 at the same scale. Both objects have extremely dark albedos. The nuclei sizes are: 9P/Tempel 1: 7.5 x 5.0 Kilometers; 103/P Hartley 2: 2.2 x 1.5 Kilometers. Credits: NASA.

The Giotto space probe first found in 1986 the surprise that the nucleus of Halley's Comet reflects about four percent of the light that falls on it (Stooke and Abergel, 1991), later NASA's Deep Space 1 probe discovered that Comet Borrelly's surface reflects just 2.4% to 3.0% of the light that falls on it. The same was found after several other NASA's interplanetary missions to the comets Wild 2, Tempel 1 and Hartley 2 (Brownlee *et al.*, 2004; Thomas *et al.*, 2013a and b).

More recently the ESA's Rosetta Mission studied in detail comet 67P/ Churyumov-Gerasimenko. Rosetta was a space probe built by the European Space Agency launched on 2 March 2004, along with "Philae", its lander module. On 6 August 2014, the spacecraft reached the comet and performed a series of maneuvers to eventually orbit the comet at distances of 30 to 10 kilometres. On 12 November, its lander module "Philae" performed the first successful landing on a comet, though its battery power ran out two days later. Communications with "Philae" were briefly restored in June and July 2015, but due to diminishing solar power, Rosetta's communications module with the lander was turned off on 27 July 2016. On 30 September 2016, the Rosetta spacecraft ended its mission by hard-landing on the comet in its Ma'at region (Biever and Gibney, 2015).

The composition of the gases emitted by the ices of the nucleus of the comet 67/P Churyumov-Gerasimenkoas measured by the Rosetta sensors are the following: Water, carbon monoxide, carbon dioxide, ammonia, methane, ethane, propane, butane, pentane, hexane, heptane, formic acid, acetic acid, acetaldehyde, ethylenglycol, propylenglycol, butanamide, methanol, ethanol, propanol, butanol, pentanol, glycine, argon, krypton, xenon, cyanogen, acetylene, hydrogen cyanide, acetonitril, formaldehyde, sodium, potassium, silicon, magnesium, hydrogensulphide, carbonylsulphide, sulphur monoxide, sulphur dioxide, carbon disulphide, nitrogen, oxygen, hydrogenperoxy, benzene, toluene, xylene, benzoic acid, naphthalene, hydrogen fluoride, hydrogen chloride, hydrogen bromide, phosphorus, chloromethane, methylamine, ethylamine, sulphur, disulphur, trisulphur, tetrasulfur, methanethiole (CH3SH), ethanethiol (C2H5SH), thioformaldehyde (CH2S), (Bardyn *et al.*, 2017).

The nucleusof the comet 67/P Churyumov-Gerasimenkoconsists mostly of dust and water ice and the density of the nucleus is 533 kilograms per cubic meter. The nucleus appears to be a low-density, highly porous (72–74 %) dusty body, similar to that of comet 9P/Tempel 1. The most likely composition mix has approximately 4 times more dust than ice by mass and 2 times more dust than ice by volume. The interior of the nucleus is homogeneous and

Figure 4 - Image of the icy nucleus of the comet 67P/Churyumov-Gerasimenko taken by the ROSETTA probe. The nucleus is bilobulated (binary) and diameters of the 2 lobes are: Large: 4.10 x 3.52 x 1.63 kilometers; Small: 2.50 x 2.14 x 1.64 kilometers. Credits: ROSETTA; ESA.

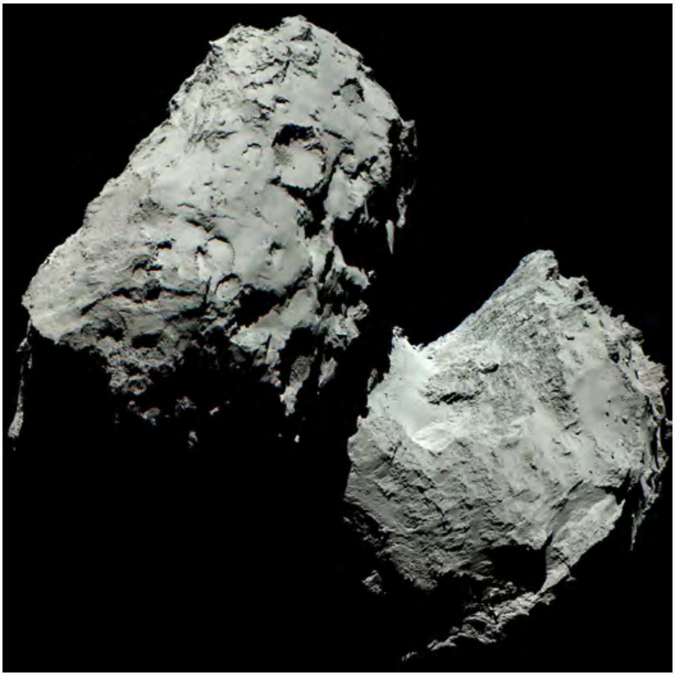

Figure 5 - Close up image of the icy nucleus of the comet 67P/Churyumov-Gerasimenko taken by the ROSETTA probe. Credits: ROSETTA; ESA.

Table 2 - Sizes of cometary nuclei visited by interplanetary probes. Sources: Festouet al., 2004- Rosetta mission, European Space Agency.

Comet	Size (in kilometers)
1P/Halley	20 x 8
19P/Borrelly	8 x 4
81P/Wild 2	5.0 (spherical)
9P/Tempel 1	7.5 x 5
103P/Hartley 2	2.2 x 1.5
67P/Churyumov-Gerasimenko,	
(Two lobes)	Large: 4.10 x 3.52 x1.63
	Small: 2.50 x 2.14 x 1.64

Table 3 - Elementary composition of cometary nuclei ice. Source: Festou et al., 2004.

Molecule	Percent (%)
Water	85
CarbonMonoxide	4
CarbonDioxide	3
Formaldehyde	2
Methanol	2
Nitrogen	1
Others (organics, silicates)	3

constant in density on a global scale without large voids (Patzold *et al.*, 2016; Figures 4 and 5).

All cometary nucleus are very dark kilometric size icy objects (see details in Festou *et al.*, 2004; A'Hearn and Combi, 2007; Thomas *et al.*, 2013a and b). By comparison, asphalt reflects seven percent of the light that falls on it. It is thought that complex organic compounds are the dark surface material. Solar heating drives off volatile compounds leaving behind heavy long-chain organics that tend to be very dark, like tar or crude oil. The very darkness of cometary surfaces enables them to absorb the heat necessary to drive their outgassing processes (Festou *et al.,* 2004; A'Hearn and Combi, 2007).

It is a well stated fact that many of the known comets moving in Earth-crossing orbits can impact our planet on geologic timescales (Melosh, 1989; French, 1998).

SPLIT COMETS

Unlike many of the monolithic asteroids, cometary nuclei are in fact not very dense and strong objects. They are made up of a central core of ice surrounded by several concentric layers of ices and carbon organic compounds. The so called "layered pile" comet nucleus model (Belton *et al.*, 2007).

Comet nuclei have a tendency to split in fragments very frequently.

Many comet nuclei split into a large number of fragments when they pass close enough to the Sun. In fact, more than 40 comet nuclei have been seen to split into several fragments in the last 150 years of astronomical observations (Chen and Jewitt, 1994; Boehnhardt, 2004).

So all the present astronomical background supports the idea of a split comet nucleus as the impactor of the Bajada del Diablo impact event.

MA'ADIM VALLIS, MARS; ANOTHER EXAMPLE OF A CLUSTER OF SMALL CRATERS

It is important to mention here that a very similar crater field is present at Ma'adim Vallis on the surface of the Southern Hemisphere of the planet Mars (Martian co-ordinates: S 20°; W 183°).

About 50 small, (200 to 700 meters in diameter), possible impact craters with raised rims are located on an oval area of 8 to 12 kilometers in diameter in the Southern Hemisphere of Mars. (Hartmann, 2003; Figure 6).

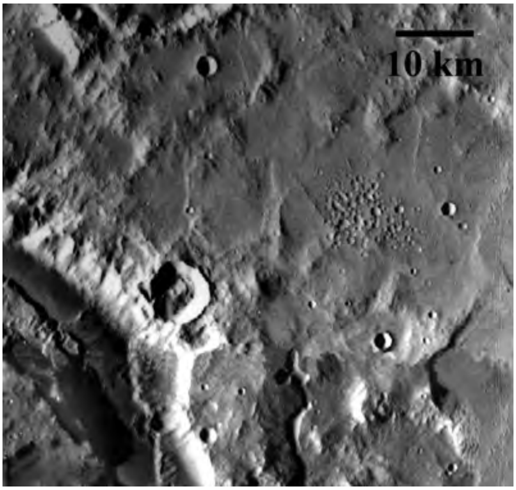

Figure 6 - Viking orbiter image of the Ma'adimVallis cluster of craters on the surface of planet Mars. Credits: VIKING- NASA

These Martian impact craters were created all together simultaneously in a single impact event like it is supposed to have happened in the Bajada del Diablo's case (Popova *et al.*, 2003).

Although its origin remains so far quite enigmatic some planetary scientists have proposed that the Ma'adim Vallis craters are the result of the impact of a small split/ fragmented cometary nucleus (Popova *et al.*, 2003).

CONCLUSION

It is thought that a small,200 meters wide, icy cometary nucleus impacted at mid Pleistocene times onan ellipsoid of 35.2 x 17.6 kilometers (a 480 square kilometer area) at Bajada del Diablo, Patagonia, Argentina, creating about 550 impact craters of less than 400 meters in diameter.

The weak comet nucleus perhaps was split in fragments by the Earth's gravity force closer or at the distance of the Roche's Limit (15,550 kilometers).

Only a few minutes later the swarm of fragments could have penetrated in the atmosphere. The smallest ice objects were probably completely burnt in the air and the largest fragments reached the ground and exploded opening about 550 impact crater depressions. All the fragments of the comet hit the ground simultaneously. The calculated total energy released in this impact event has been estimated as 200 to 400 Megatons of TNT.

Today only about 200 impact craters have survived the local erosive processes actives in the zone since the impact event.

ACKOWLEDGEMENTS

To the Argentinian geologists Jorge Rabassa, Ricardo N. Alonso and Hugo Corbella for their help and valuable comments on the case. To William K. Hartmann (PSI, Arizona, USA) for the copy of the Viking image of the Ma'adim Vallis cluster of craters on Mars. This research was funded by several yearly Near Earth Objects grants from The Planetary Society, Pasadena, California, USA.

REFERENCES

Acevedo, R.D.; Ponce, J.F.; Rocca, M.C.L.; Rabassa, J. y Corbella, H. (2007). Filú-Có plateau: the major impact crater field of Bajadadel Diablo strewnfield, Argentine Patagonia. *GeoSur Meeting, Santiago de Chile, 19-20 November, Abstracts*, 2.

Acevedo, R.D.; Ponce, F.; Rocca, M.; Rabassa, J. y Corbella, H. (2009). Bajada del Diablo impact crater-strewn field: The largest crater field in the Southern Hemisphere. *Geomorphology*, 110(3-4), 58-67.

Acevedo, R.D.; Ponce, J.F.; Rabassa, J.; Corbella, H., y Rocca, M. (2010). Bajada del Diablo. Un excepcional campo de cráteres producidos por meteoritos en el centro del Chubut. *Ciencia Hoy*, 20(18), 25-35.

Acevedo, R.D.; Prezzi, C.; Orgeira, M.J.; Rabassa, J.;

Corbella, H.; Ponce, J.F.; Martinez, O.; Vasquez, C.; Subias, I.; Gonzalez, M. y Rocca, M. (2011). Bajada del Diablo, Patagonia, Argentina: The impact of a split comet? *74th Annual Meeting of the Meteoritical Society*, London, United Kingdom.

Acevedo, R.D.; Rabassa, J.; Ponce, J.F.; Martinez, O.; Orgeira, M.J.; Prezzi, C.; Corbella, H.; Gonzalez-Guillot, M.; Rocca, M.; Subias, I. y Vasquez, C. (2012). The Bajada del Diablo astrobleme-strewn field, central Patagonia, Argentina: Extending the exploration to surrounding areas. *Geomorphology*, 169-179, 151-164.

A' Hearn, M.F. y Combi, M.R. (2007). Deep Impact at Comet Tempel 1. *Icarus*, 191, 597.

Bardyn, A. *et 25 colleagues* (2017). Carbon-rich dust in comet 67/P Churyumov-Gerasimenko measured by COSIMA/ROSETTA. *Monthly Notices of the Royal Astronomical Society*, 469, S712-S722.

Belton, M.J.S. *et 14 colleagues* (2007). The internal structure of Jupiter family cometary nuclei from Deep Impact observations: The "talps" or "layered pile" model. *Icarus*, 191, 573-585.

Biever, C. y Gibney, E. (2015). Philae comet lander weakes up and phones home. *Nature*, doi: 10.1038/nature.2015.17756

Boehnhardt, H. (2004). *Split Comets*. In: M.C. Festou, H.U. Keller y H.A. Weaver (Eds.), 2004. *Comets II*, pp. 301-316. Tucson, USA. The University of Arizona Press.

Bottke, W.F. Jr.; Cellino, A.; Paolicchi, P. y Binzel, R.P. (2002*). Asteroids III*, Tucson, USA, University of Arizona Press, 785 pp.

Brownlee, D.E. *et 11 colleagues* (2004). Surface of young Jupiter family Comet 81P/Wild 2: view from Stardust Spacecraft. *Science*, 304, 1764-1769.

Campins, H. y Fernandez, Y. (2002). Observational constraints on surface characteristics of comet nuclei. *Earth, Moon and Planets*, 89, 117-134.

Corbella, H. (1987). Agrupamientos de cráteres por posible impacto, Bajada del Diablo, Chubut, Argentina. *Revista Asociación Argentina Mineralogía, Petrología y Sedimentología*, 18, 1-67.

Chen, J. y Jewitt, D. (1994). On the rate at which comets split. *Icarus*, 108, 265-271.

Festou, M.C.; Keller, H.U. y Weaver, H.A. (2004). *Comets II*. Tucson, USA, University of Arizona Press, 745 pp.

French, B.M. (1998). *Traces of catastrophe*. Lunar and Planetary Institute (LPI) Contribution No. 954, USA, 120 pp.

Grieve, R.A.F. (1990). Impact cratering on the Earth. *Scientific American*, 262, 66-73.

Grieve, R.A.F. (2001). Impact cratering on Earth. In: G.R. Brooks (Ed.), A Synthesis of Geological Hazards in Canada. *Geological Survey of Canada*, 548, 207-224.

Krinov, E.L. (1966). *Giant Meteorites*. New York, USA, Pergamon Press, 397 pp.

Hartmann, W.K. (2003*). A Traveller's Guide to Mars: The Mysterious Landscapes of the Red Planet*. New York, USA, Workman Publishing Company, 450 pp.

Melosh, H.J. (1989*). Impact cratering a geologic process.* Oxford, United Kingdom, Oxford University Press, 245 pp.

Norton, O.R. (2002). *Encyclopedia of meteorites*. Oxford, United Kingdom, Oxford Univesity Press, 374 pp.

Patzold, M. *et 15 colleagues* (2016). Ahomogeneus nucleus for comet 67/P Churyomov-Gerasimenkofrom its gravity field. *Nature*, 530, 63-65.

Ponce, J.F.; Acevedo, R.D.; Rocca, M.C.L.; Rabassa, J. y Corbella, H. (2008). Ubicación geográfica y localización geológica de los cráteres de impacto de Filú-Có (Bajada del Diablo), Provincia del Chubut, República Argentina. *Actas XVII Congreso Geológico Argentino*, 3, 1241-1242.

Popova, O.; Nemtchinov, I. y Hartmann, W.K. (2003). Bodies in present and pastmartian atmosphere and effects on cratering processes. *Meteoritic and Planetary Sciences*, 38, 905-923.

Rocca, M.C.L. (2006). Two new potential meteorite impact sites in Chubut Province, Argentina. *Meteoritics and Planetary Science*, 41 (8), A151.

Stooke, P.J. y Abergel, A. (1991). Morphology of the nucleus of Comet P/Halley. *Astronomy and Astrophysics*, 248, 656-668.

Thomas, P.C. *et 24 colleagues* (2013a). The nucleus of Comet 9P/Temple 1: Shape and geology from two flybys. *Icarus*, 222, 453-466.

Thomas, P.C. *et 18 colleagues* (2013b). Shape, density and geology of the nucleus of Comet 103P/Hartley 2. *Icarus*, 222, 550-558.

Wilkening, L.L. (1983). *Comets.* Tucson, USA, University of Arizona Press, Tucson, 766 pp.

Zolensky, M.E. *et 75 colleagues* (2006). Mineralogy and Petrology of Comet 81P/Wild 2 Nucleus Samples. *Science*, 314, 1735-1739.

Recibido: 30/05/2019 - Aceptado: 07/06/2019 - Publicado: 08/08/2019