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METEORITE IMPACT CRATERS AND EJECTA IN SOUTH AMERICA: A BRIEF REVIEW

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Abstract

The first catalogue of impact craters sites in South America is presented here. Proximately thirty proven, suspected and disproven structures have been identified by several sources in this continent until now. But everyone events proposed here aren´t really produced by impacts at all. About some of them reasonable doubts exist. Argentina and Brazil are leading the list containing almost everything detected. In Bolivia, Perú, Chile, Colombia and Uruguay only a few were observed. The rest of countries are awaiting for new discoveries.

Keywords: Impact craters; South America.

Introduction

Today, impact cratering is recognized as the dominant surface-modifying process in the planetary system. During the last forty years, planetary scientists have demonstrated that our Moon, Mercury, Venus and Mars are all covered with meteorite impact craters. However, only recently it has been accepted the fact that impact cratering is an important geologic process working on the Earth's surface too.

Impact cratering involves high velocity collisions between solid objects, typically much greater than the velocity of sound in those objects. Such hyper-velocity impacts produce physical effects such as melting and vaporization, which do not occur in familiar sub-sonic collisions. On Earth, ignoring the slowing effects of travel through the atmosphere, the lowest impact velocity with an object from space is equal to the gravitational escape velocity of about 11 km/s. The fastest impacts occur at more than 70 km/s, calculated by summing the escape velocity from Earth, the escape velocity from the Sun at the Earth's orbit, and the motion of the Earth around the Sun. The median impact velocity on Earth is about 20 to 25 km/s.

Impacts at these high speeds produce shock waves in solid materials, and both impactor and the material impacted are rapidly compressed to high density. Following initial compression, the high-density, over-compressed region rapidly depressurizes, exploding violently, to set in train the sequence of events that produces the impact crater. Impact-crater formation is therefore more closely analogous to cratering by high explosives than by mechanical displacement. Indeed, the energy density of some material involved in the formation of impact craters is many times higher than that generated by high explosives. Since craters are caused by explosions they are nearly always circular, only very low-angle impacts cause significantly elliptical craters.

It is convenient to divide the impact process conceptually into three distinct stages: (1) initial contact and compression, (2) excavation, (3) modification and collapse. In practice, there is overlap between the three processes with, for example, the excavation of the crater continuing in some regions while modification and collapse is already underway in others.

Basic definitions

Obviously, not all bowl-shaped depressions and circular structures are meteorite impact sites. Volcanic calderas and craters may mimic them at first glance. Sinkholes and karstic low basins are very similar too. However, a few guidelines help to avoid confusion. Volcanic structures usually show lava flows and hardly ever have raised rims. Maars are the only exception. Sinkholes do not have raised rims.

The general classification of impact site is the following:

Simple crater: it is the smalest impact structure, like a bowl-shaped depression less than 4.0 km in diameter. One of their main characteristics is the presence of a raised rim. At the rim the local strata are upturned and even overturned. The depression and the area all arround the crater is filled by broken and mixed rock (breccia).

Complex structures: They are large impact structures (from 4.0 km up to 400 km in diameter) characterized by an almost perfect circular shape, a central uplifted region, a generally flat floor, and extensive inward collapse around the rim.

Complex impact structures can be classified in:

1) Central peak impact structures.
2) Peak ring impact structures.
3) Multi-ring impact structures.

Relatively small-diameter craters are bowl shaped with raised rims (simple-type craters). As crater diameter increases, slumping of the inner walls of the rim and rebounding of the depressed floor create progressively larger rim terracing and central peaks (complex impact structures). At larger diameters, the single central peak is replaced by one or more peak rings, resulting in what is generally termed "impact basin" or "multi-ring impact basins". The interiors of complex structures are also partly filled with breccias and impact melt rocks.

Breccia is a rock composed of angular fragments of several minerals or rocks in a matrix, that is a cementing material and it may be similar or different in composition to the clasts. A breccia may have a variety of different origins, as indicated by the named types including sedimentary, tectonic, igneous, impact and hydrothermal breccias. Meteorite fragments recovered within or arround a crater are the strongest evidence for an impact origin, but they cannot be obtained from every site. Fragments are found only at the smaller craters and they weather quickly in the terrestrial environment. For impacts events on the Earth that form simple-type craters larger than aproximately 1.0 kilometer in diameter, the shock pressures and temperatures produced upon impact are sufficient to completelly melt and even vaporize the impacting body and some of the target rocks. So no meteorite especimens survive in such cases. In such cases, the recognition of a characteristic suite of rock and mineral deformations, termed "shock metamorphism" that is produced uniquely by extreme shock pressures, is indicative of an asteroid or comet impact origin. Examples of shock effects include conical fractures known as "shatter cones", microscopic deformation features in minerals, particularly the development of so-called "Planar Deformation Features" (PDFs) in silicates, the occurrence of various solid state glasses (diaplectic glasses) and hight-pressure polimorphs variations of minerals (high pressure forms of quartz: coesite, stishovite), and rocks melted by the intense heat of the impact.

Shatter cones are rare geological features that are only known to form in the bedrock beneath meteorite impact craters. They are evidence that the rock has been subjected to a shock with pressures in the range of 2-30 GPa. Shatter cones have a distinctively conical shape that radiates from the top (*apex*) of the cones repeating cone-on-cone in large and small scales in the same sample. Sometimes they're more of a spoon shape on the side of a larger cone. At finer-grained rocks such as limestone, they form an easy to recognize "horsetail" pattern with thin grooves (*striae*). Coarser grained rocks tend to yield less well developed shatter cones, which may be difficult to distinguish from other geological formations such as slickensides. Geologists have various theories of what causes shatter cones to form, including compression by the wave as it passes through the rock or tension as the rocks rebound after the pressure subsides. The result is large and small branching fractures throughout the rocks. Shatter cones can range in size from microscopic to several meters. A very large example of more than 10 meters in length is known from the Slate Islands impact structure, Canada. The azimuths of the cones's axes typically radiate outwards from the point of impact, with the cones pointing upwards and toward the center of the impact crater, although the orientation of some of the rocks have been changed by post-cratering geological processes at the site.

Planar Deformation Features, or **PDFs**, are optically recognizable microscopic features in grains of silicate minerals (usually quartz or feldspar), consisting of very narrow planes of glassy material arranged in parallel sets that have distinct orientations with respect to the grain's crystal structure. PDFs are only produced by extreme shock compressions on the scale of meteor impacts. They are not found in volcanic environments. Their presence therefore is a primary criterion for recognizing that an impact event has occurred.

Coesite is a form (polymorph) of silicon dioxide that is formed when very high pressure (2–3 gigapascals) and moderately high temperature (700 °C) are applied to quartz. Coesite was first created in 1953. In 1960, coesite was found by Edward C.T. Chao, in collaboration with Eugene Shoemaker, to naturally occur in the Barringer Crater, which was evidence that the crater must have been formed by an impact. The presence of coesite in unmetamorphosed rocks may be evidence of a meteorite impact event or of an atomic bomb explosion. In metamorphic rocks, coesite commonly is one of the best mineral indicators of metamorphism at very high pressures (UHP, or ultrahigh-pressure metamorphism). Such UHP metamorphic rocks record subduction or continental collisions in which crustal rocks are carried to depths of 70 km or more. Coesite also has been identified in eclogite xenoliths from the mantle of the earth that were carried up by ascending magmas. Kimberlite is the most common host of such xenoliths. The molecular structure of coesite consists of four silicon dioxide tetrahedra arranged in a ring. The rings are further arranged into a chain. This structure is metastable within the stability field of quartz: coesite will eventually decay back into quartz with a consequent volume increase, although the metamorphic reaction is very slow at the low temperatures of the Earth's surface. Some terrestrial structures have morphological characteristics consistent with both a simple-type craters or a complex impact structure, but lack either pieces of the impacting body (meteorites) or definitive signs of shock metamorphism. This may be because suitable samples can not be recovered as they are submerged beneath a deep circular lake, buried under post-impact sedimentary rocks, or almost completelly eroded. Continued investigation may yet produce evidence of shock metamorphism at some of these possible impact craters or structures (Grieve 1990, Grieve 2001).

Impact craters in South America

We are now going to review each of the reported possible or confirmed impact craters/structures in the continent, country by country.

Argentina

Argentina has a total surface of 2,776,888 square kilometers.

There is only one review paper (in Spanish) devoted to the possible and confirmed impact craters of Argentina (Acevedo and Rocca 2005).

The following possible and confirmed meteorite impact craters/structures have been reported for this nation:

1) Campo del Cielo (S 27º 30', W 61 º42')

The Campo del Cielo meteorite field consists, at least, of 20 meteorite craters with an age of about 4000 years. The area is composed of sandy-clay sediments of Quaternary-Recent age. The impactor was an Iron-Nickel Apollo-type asteroid (meteorite type IA) and plenty of meteorite specimens survived the impact. Impactor's diameter is estimated about 10 meters (Liberman *et al.* 2002). The impactor came from the SW and entered into the Earth's atmosphere in a low angle of about 9º. As a consequence, the asteroid broke in many pieces before creating the craters. Even a tentative solar orbit was calculated for the impactor (Renard and Cassidy 1971). The first meteorite specimens were discovered during the time of the Spanish colonization. Craters and meteorite fragments are widespread in an oval area of 18.5 x 3 kilometers (SW-NE), thus Campo del Cielo is one of the largest meteorite's crater fields known in the world (Cassidy 1967, 1968, 1971, Cassidy and Renard 1996, Cassidy *et al.* 1965). The craters show raised rims and overtunrned strata at the rim. Most of the craters of Campo del Cielo strewn field (in fact 16 of them) are penetration funnels and not explosion craters. Only the craters numbered 1 to 4 are probably explosion craters. These four craters differ from the others in that they are 1) deeper and/or have greater original depth/diameter ratios, 2) are more circular as opposed to the ellongated nature of the other sixteen, 3) do not have large magnetic anomalies associated and, 4) have meteorite fragments of the disrupted impacted asteroid within the ejecta blanket, (Wright *et al.* 2006, Wright *et al.* 2007).

The following is a review of the most important craters of the Campo del Cielo area:

Crater 1: This crater is named "Hoyo de la Cañada". It lies near the center of the strewn field. It is elliptical in shape and its major dimention is 105 meters from rim to rim. A shallow gully found in the rim gives it its name. The crater is presently 2 meters deep at its deepest.

Crater 2: Named "Hoyo Rubin de Celis" after the explorer Miguel Rubin de Celis who led an expedition to the area in 1783. It has a diameter of 70 meters and is the deepest crater (5 meters) and probably the least eroded. An extensive radial trench through the crater and its rim showed many features common to impact craters of its size, like upthrust of the rim by about 0.5 meters and inversion of the stratigraphy outside of the rim. Drilling at the center showed the presence of "clay breccias" at depths of 15 meters bellow the present floor.

Crater 3: It is called "Laguna Negra" because of the lake that filled it. It is the largest impact crater of the strewn field with a diameter of 115 meters. It is quite shallow, only 2 meters deep at its center. It is no doubt an explosion crater and not a penetration funnel as most of the other craters in the same strewn field.

Crater 4: Crater 4 is about 85 meters in diameter and 1.5 meters deep.

Crater 5: Crater 5 is shallow and with an ill-defined rim. It is about 45 meters in diameter.

Crater 6a and 6b: These twin craters share a common East-West rim. The larger, 6a, has a diameter of 35 meters, while the smaller is 20 meters across.

Crater 7: Crater 7 is elliptical in outline with rim-to-rim dimentions of 96 x 74 meters.

Crater 8: Also an elliptical penetration funnel, it has dimentions of 46 x 28 meters.

Crater 9: Inside this crater, a penetration funnel again, called "La Perdida" several meteorite pieces were discovered weighing in total about 5,200 kilograms.

Crater 10: It is called "Gómez", (diameter about 25 m) and it is a penetration funnel and not an explosion crater. Inside it a huge meteorite specimen called "Chaco", of 37,400 kg. was found in 1980. It is so far the second heaviest meteorite ever found in the World.

Crater 13: It a small crater and its rims are not very well defined. It is a penetration funnel and not an explosion crater. An huge meteorite specimen with a weight of 14,850 kg. was found inside this crater (Wright *et al*. 2006).

Crater 17: Again it is a penetration funnel and not an explosion crater. A large meteorite specimen with a weight of 7,850 Kg. was found in this crater.

The craters of Campo del Cielo represent a unique site in the World and their study will continue from many decades.

2) Bajada del Diablo, Chubut (S 42º 45', W 67º 30') Figure 1.

A very remarkable site of a new very large meteorite impact craters field is present in this area. They were discovered in the 80's (Corbella 1987). More than 100 small simple-type craters are widespread over an area of 27 x 15 kilometers (Rocca 2006, Acevedo *et al.* 2007, Ponce *et al.* 2008). More than 60 craters have diameters between 360 and 100 meters. 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 basaltic plateaux and piroclastic rocks. Areas exposing Pleistocene and Recent fluvial sediments show no crater so the impact event was not very recent. No doubt, many craters have been erased by the Recent fluvial erosion processes and what we see today is just a fraction of the original population of craters.

This craters field is probably the result of the impact of a 100 to 200 meters wide rubble-pile type asteroid or a cometary nucleus 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. Age of this impact is estimated between 0.13 and 0.78 Ma. (Acevedo *et al.* 2009). When meteorite showers reach the ground they distribute themselves into a strewn field which usually defines an elliptical shaped area called, the dispersion ellipse. 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 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 images. Most probably, this craters field is the result of the impact of a 100 to 200 meters wide rubble-pile type 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. This site could be the largest meteorite impact crater field known in the World. Further investigation of this interesting site is in progress.

Figura 1 - Bajada del Diablo

Figura 2 - Bajo Hondo

3) Bajo Hondo, Chubut (S 42º 15, W 67º 55') Figure 2.

Bajo Hondo is a very puzzling crater in Chubut Province, Patagonia. It is a possible impact crater (Gorelli 1998) but still needs *in situ* confirmation. Diameter is 4.8 kilometers. This crater is in fact very similar to Barringer's crater, USA, but of a much more gigantic size. Bajo Hondo has a 100 to 150 meters raised rim. In the aerial photos there are also visible some 50-60 meters wide boulders resting on the crater's rim. Bajo Hondo is located in the Somuncura plateau, 10 km. SE to the Sierra de Talagapa stratovolcano. The Sierra de Talagapa, which is part of the Somuncura plateau, consists of a large 25 x 10 kilometer stratovolcano. The large Talagapa volcanic center was active during late Oligocene-Miocene times erupting both pyroclastic ignimbritic flows and basaltic lava flows (Ardolino 1987). Bajo Hondo has been interpreted as a collapsed basaltic caldera (Ardolino and Delpino 1986, Ardolino 1987). Close examination of satellite images (LANDSAT, X-SAR), aerial photographs, its published geologic map and a review of the geological characteristics of Bajo Hondo reveal flaws in the volcanic caldera interpretation. The lava in the surrounding plateaux was no doubt erupted from Sierra de Talagapa volcano during the Oligocene-Miocene. The crater is located on those older lava floods. The association of some lava floods to Bajo Hondo is quite doubtful. Probably the reported ones were erupted by Sierra de Talagapa and not by Bajo Hondo itself. A reported "pyroclastic cone" located in the inner Western rim of Bajo Hondo (Ardolino and Delpino 1986) was probably erupted by Talagapa and now it is just an eroded and collapsed part of Bajo Hondo's rim. There is also good evidence of uplifted strata exposed in the inner rims of Bajo Hondo. Uplifted Talagapa's basaltic rock strata were probably misinterpreted as "vertical or almost vertical basaltic dykes located in the inner rims of Bajo Hondo" by the volcanologists. Rocks exposed on Bajo Hondo's rims are clearly pyroclastic: 1) lapilli–like basaltic breccia enclosing irregular clasts and blocks up to 3 meters in diameter, and 2) a great abundance of 13 to 7 centimetre wide brown-reddish scoriaceous bombs showing aerodynamic shapes and deformation. The peculiar shape of those glass bomb bodies prove that whilst still in a viscous state they must have flown through the air i.e. were ballisticaly transported. The same type of rocks are present in Lonar Lake's crater rim, a well confirmed impact crater in basalt in India. Bajo Hondo is probably too big to be a maar. Rocca (2003c) and Rocca (2005) believe Bajo Hondo could be in fact a misinterpreted gigantic simple-type impact crater located on a volcanic plateau. Lonar Lake impact crater in India (a 1.8 kilometers wide simple-type impact crater on basalts) was misinterpreted as a volcanic caldera for many decades. The age of Bajo Hondo crater is estimated in less than 10 Ma. If confirmed as a new simple-type impact crater in basalt then Bajo Hondo will be very interesting to compare with the extra-terrestrial craters on basalt of the Moon, Mars, Venus and Mercury. However, recent trip to this place seem to confirm their volcanic origin.

4) Meseta del Canquel, Chubut (S 44º 28', W68º 35') Figure 3.

Three possible simple-type impact craters located in a Y-shape configuration on a olivine-basalt plateau were reported from Landsat satellite imagery. Craters show raised rims. Diameters are A: 1.3 kilometers, B: 0.8 kilometers and C: 0.6 kilometres. Age is estimated in less than 20 Ma. (Rocca 2006).

5) Meseta de la Barda Negra, Neuquén (S 39º 10', W 69º 53') Figure 4.

Recent efforts to indentify additional impact craters in Argentina, making use of LANDSAT imagery and aerial photographs, have identified a possible new example in this category in Patagonia (Rocca 2004a). It is an isolated crater (diameter 1.5 kilometers) in the middle of a large brown basaltic plateau. When aerial photographs of the area were obtained they proved this crater was in fact similar to Barringer's meteor crater in Arizona, USA. It has a raised rim. The crater has been mapped as a "salitral" (salitrous basin) affecting Basalto Zapala (top) and Collón Cura Formation (cineritic tuffs and tuffs) at the bottom. It has been described there a typical "bajo sin salida" containing blocks, conglomerates and sands with diatomites (Tula mine) as a window in the basaltic plateau (this is in no conflict with the hypothesis of an impact crater). The lava in the surrounding plateau was erupted from ground fissures during the Miocene (radiometric ages for the basalt: 14-10 Ma). The crater is located affecting those older lava floods. Then, age of Barda Negra's crater is estimated in less than 10 Ma. (Ocampo *et al.* 2005). Recent *in situ* research results were not conclusive about the origin of this depression. There is a report in conflict with an impact origin for this crater (Wright S.P. private communication). However it is not conclusive (Garrido A. private communication). The crater could be in fact a volcanic structure like, e.g. a maar or a still could be a new meteorite impact crater. This crater demands more investigation to be rejected or confirmed as a real impact crater.

6) Los Mellizos Structure, Santa Cruz (S 47º 20', W 70º 00')

Los Mellizos structure is a large circular depression in the hilly plateau named Meseta del Deseado. The crater forms a circular basin with a rim-to-rim diameter of 15 kilometers. The rim consists of a circular ring of low hills. This circular feature has also a clear difference in its color (light orange to pink) when compared with the color of the surrounding area (brown). Rocks exposed in the surrounding areas are darker than the rocks exposed in the circular structure. The crater seems to be eroded to the point that only in a few places does the present edge of the rim correspond to the original lip of the crater. Radial faults are present in this structure. In the North, a small river flows around the circular rim of the structure and another small river crosses the whole structure from the SW to NE. A central peak is apparently exposed and it is visible in the radar images of the German's DLR X-SAR. At present, the geology of this entire area is not known in very detail. The surroundings of the structure are made up of volcanic formations from the Middle Jurassic age (170-140 Ma.) Chon Aike Formation. Rocks exposed there are rhyolitic ignimbrites, piroclastic rocks and tuffs. This structure is quite old and quite eroded and it could represent a new example of an impact structure formed in siliceous volcanics. This could be the largest impact structure of mainland Argentina (Rocca 2003, a and b, Rocca 2007).

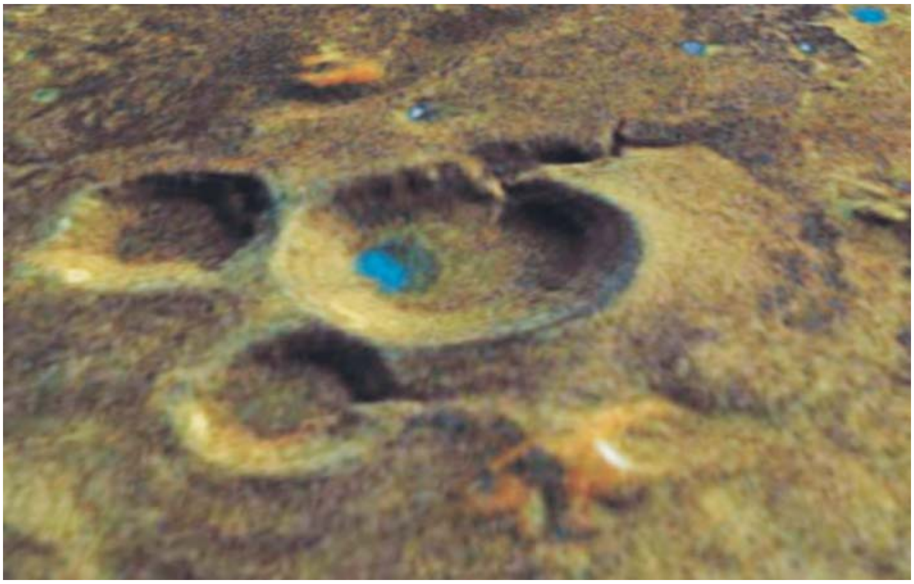

Figura 3 - Canquel

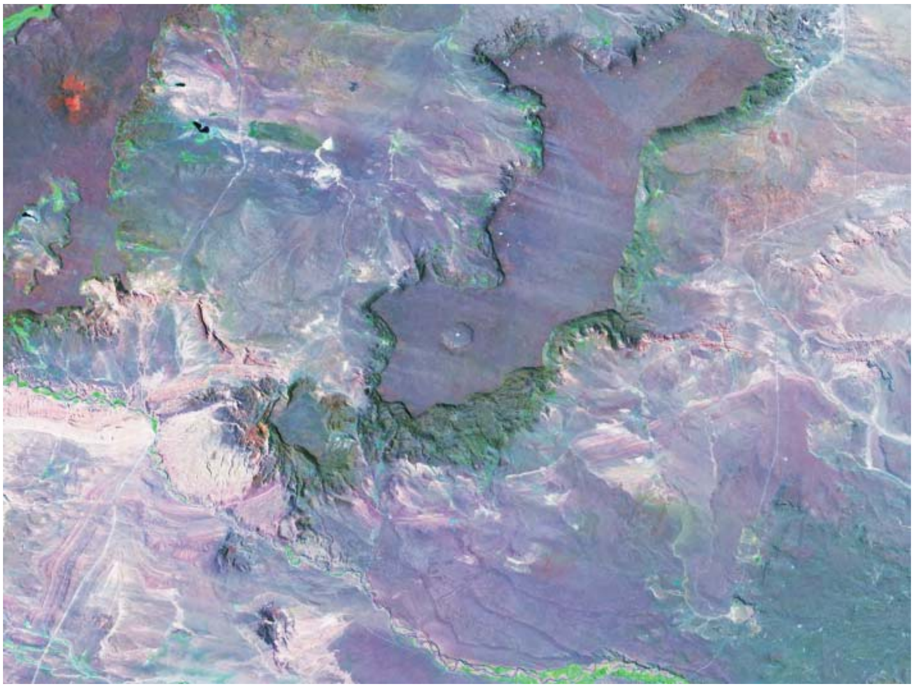

Figura 4 - Barda Negra

7) Gran Altiplanicie Central, Santa Cruz (S 48º 25', W 70º 08')

Recent efforts to indentify additional impact craters in Argentina, making use of Landsat imagery and aerial photographs, have identified a possible eroded simple-type crater in the Meseta de la Gran Altiplanicie Central (Rocca 2003a). It is an isolated crater (diameter 1.0 kilometers) in the middle of a large brown basaltic plateau. When aerial photographs of the area were obtained they proved this crater has a raised rim. The lava in the surrounding plateau was erupted from ground fissures during the Miocene (radiometric ages for the basalt: 12-11 Ma.). The crater is located affecting those older lava floods. Then, age of this crater is estimated in less than 11 Ma. Further research of this site is in progress.

8) Salar del Hombre Muerto, Puna, Salta (S 25º 12', W 66º 55')

As a part of an on-going project to discover meteorite impacts a potential new large meteorite impact crater field was found by the examination of Landsat color images and aerial photographs (Rocca 2004b). Possible 10 small (diameters from 90 to 250 meters) fresh simple craters are located on a Quaternary-Recent aluvional cone of sedimentary deposits. The diameter of the largest crater is 250 meters. Craters are widespread in an oval area of 5 x 4.5 kilometers. These craters are not located on a tectonic fault. They are not doline features. Most probably they are the result of a meteorite shower. Their age is estimated in less than 0.5 Ma.

9) Antofalla's crater, Salar de Antofalla, Catamarca (S 26º 15', W 68º 00')

A possible large simple-type impact crater of 750 meters in diameter has been reported in the SE corner of the Salar de Antofalla (Fielding and Alonso 1988, Alonso and Fielding 1992). It was discovered from the examination of Landsat satellite imagery. It seems to be well preserved although its rims are a bit eroded and it is placed on ignimbrite rocks of Cenozoic age. This crater demands *in situ* research to be confirmed.

10) Valle de Santa María, Catamarca (S 26º 44', W 66º 00')

A possible new simple-type impact crater has been reported recently for the Valle de Santa María, in Catamarca. It was studied by the examination of Landsat satellite images and aerial photos. The possible crater has a diameter of 300 meters, it has raised rims, and seems to be a bit eroded. It is located in a desertic area, on sandstones of the Andalhuala Formation which are dated as Miocene-Pliocene (Gabriloff 2008). Further research on this site is in progress.

11) South Atlantic Geophysical Anomaly: Islas Malvinas. (S 51º 00', W 62º 00') Figure 5.

Although very speculative, a possible large impact structure has been proposed to be in the Patagonian continental shelf, at the Malvinas Islands in front of Santa Cruz Province. A possible large Carboniferous-Permian impact crater site could be present in the Malvinas Islands. A 200 kilometers in diameter circular Bouguer gravity anomaly has been reported in the ocean to the NW of Malvinas Islands and it is interpreted as a large Late Paleozoic impact site (Rampino 1992, a and b). A circular structure, of about 200 kilometers in diameter it is located underwater, a few kilometers offshore to the NW of the Gran Malvina Island and it is covered by more recent sediments. In the gravity field maps there is a central circular area of low negative gravity values surrounded by a 200-250 km circular ring of positive values. The structure could be a complex impact structure of the gigantic central peak ring basin type. To the immediate south rim of this anomaly the Paleozoic platform is transected by WNW-ESE-oriented, northward dipping thrust sheets that may have a similar trend to structures observed onshore in Gran Malvina Island. Both satellite and marine gravity data exhibit relatively low anomalies just to the north of these thrusts. These low gravity anomalies possibly indicate the presence of a basin. The southern margin of gravity low corresponds perfectly with the position of the thrusts. Aeromagnetic data also exhibit a relatively low circular anomaly in the same area. There are also seimic reflection profiles of this structure in possesion of the Western Geco Petroleum Company, United Kingdom. Those seismic reflection profiles show a basin, probably a sedimentary one, in the area of the circular structure (Richards P. private communication). This basin has been interpreted by the British Geological Survey's geologists as a complex sedimentary basin of Permo-Triassic age and recently re-dated as Carboniferous-Permian (Aldiss D. private communication, Richards P. private communication). This site demands more and detailed research to be confirmed or probably rejected as a new large impact site.

12) Río Cuarto, Córdoba (S 32º 52', W 64º 14')

First noticed by airplane pilot R. Lianza, the Río Cuarto craters are, at least, eleven oblong rimmed depressions ranging in size from "Crater A" of 4.5 x 1.1 kilometers, down to structures several meters wide (Lianza 1992). The largest structures have poorly defined rims at either end of the long axes but well defined rims to either side reaching 3 to 7 meters above the surrounding plains. They are aligned in parallel in a NE-SW direction and they span a line of about 30 km (Schultz and Lianza 1992). The region is covered by Quaternary loess. Exploration *in situ* revealed frothy glass impactites and two H chondrite meteorite fragments, one which was enveloped in a shell of glassy impactite material. Glass contains baddeleyite, rare shocked quartz grains and elevated Cr, Ni and Ir abundances (Koeberl and Schultz 1992). These oval depressions resemble the structures produced in high speed gun laboratory experiments of low angle impacts. In this hypothesis, the impactor, a stony (H-type chondrite) asteroid of about 200 meters, entered the Earth's atmosphere in a very flat angle from the NE (Bunch and Schultz 1992). Then it broke into several pieces and impacted. The age of that event was estimated in less than 10,000 years (Schultz and Beatty 1992, Schultz *et al.* 1994, Aldahan *et al.* 1995, 1997). However, by satellite imagery survey, more than 400 new oval features that bear a strong similarity to those previously described were also discovered and reported in the same area (Bland *et al.* 2001, 2002, Cione *et al.* 2002). There were reports of stratigraphic sections at those oval structures which demostrate that there are no truly raised rims but instead dune forms and no ejecta accumulation anywhere (Cione *et al.* 2002). *In situ* research at those new oval structures revealed more glass and new meteoritic samples: both chondritic and achondritic specimens were found associated in one of the new oval depressions. Glass was also found in several of the new features. New research indicates an eolian (deflation basins), rather than an impact origin for those elongated depressions. There are nowadays doubts and controversy concerning the original hypothesis of an oblique impact in Río Cuarto. However, it is clear that the glass found at Río Cuarto's structures is derived from an impact event. It may be a distal, rather than proximal ejecta. Age of glasses was re-estimated in about 570.000 years. Apparently there are two impact glass layers in the area, one of half a million years ago and the other of about 10,000 years. This glass may be tektite glass from an impact event around half a million year ago representing not an oblique impact but a new tektite strewn field. Anyway, source crater remains unknown. The situation is so far very unclear and the area demands more and more detailed research.

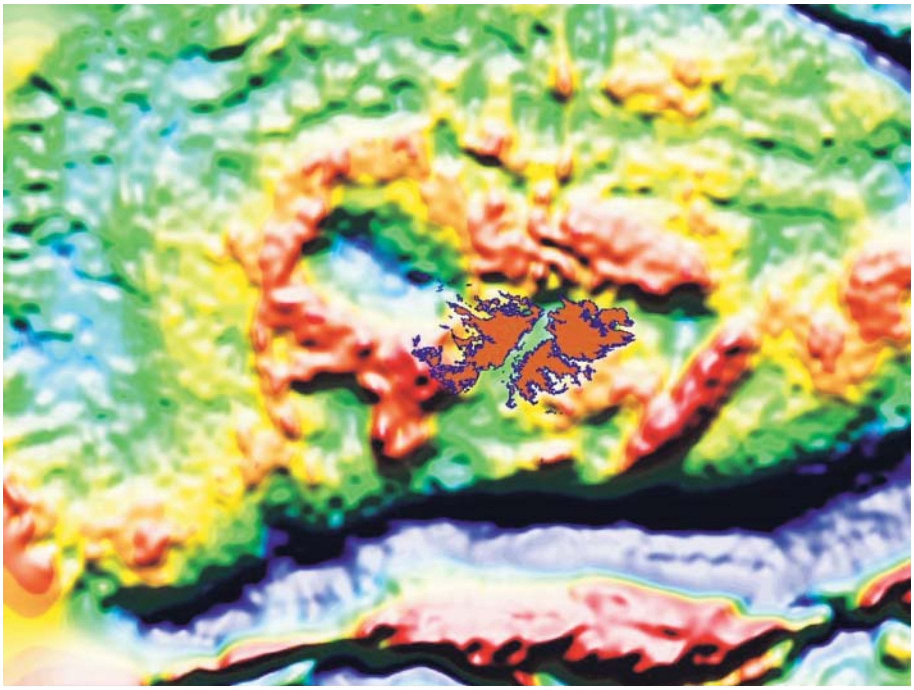

Figura 5 - Malvinas

13) Cerro Morro de Cuero, Mendoza (S 34º 15', W 69º 32')

This possible crater was detected by aerial photograph and satellite (Landsat and CBERS) imagery (Martini and Asato 2004). The crater (diameter 600 meters) is located on mountains of the Andean ridges.

Age suggested for this simple-type crater is early Holocene. However, recent in situ research revealed this crater is in fact a volcanic cone (Asato private communication).

14) The impact ejecta of the Atlantic coast, Buenos Aires and La Pampa provinces: The "Escorias" and "Tierras cocidas"

So far, only one positive new impact crater and one possible impact structure are known in this area. But strong evidence for several asteroid or comet impact events exists in the form of geochemical data and research of the glassy impactite layers enclosed in the loessoid deposits of Tertiary-Quaternary age exposed in the cliffs along the Atlantic coast of Buenos Aires Province. Those impactites are locally named as "escorias" (scoriaceous pieces of green-brown glass) and "tierras cocidas" (a brick-like red orange rock), and they are widespread as layers in several sites. At present, they are interpreted by most of the scientists as distal asteroid or comet impact ejecta materials. Early in the XX Century there was a strong discussion about the origin of these materials. On the one hand there was the argentinian naturalist Florentino Ameghino who believed the escorias and tierras cocidas were the product of ancient prehistoric man's made wild straw fires (Ameghino 1908, 1909 a, b, c and d, Ameghino 1910, Romero 1912) On the other hand there were scientists who believed these materials were of a volcanic origin (Outes *et al.* 1908, Steinmann 1907, Outes and Bucking 1910, Willis 1912, Wright and Fenner 1912). Since the death of Ameghino in 1911 very little attention was put on these materials so even the most important contributions to the geology of the area only made a very brief mention of the escorias and tierras cocidas (Frenguelli 1920, Kraglievich 1952). Recently, there were some other hypothesis about the origin of the escorias and tierras cocidas (Cortelezzi 1971) and some spread vitreous material like "escorias", interpreted as possible fulgurites, have been shown in the area too (Volkheimer *et al.* 2003). Baddeleyite clusters were found within the glass matrix of the escorias and they were produced by breakdown of zircon due to high transient temperatures. The presence in the glass of quartz grains showing Planar Deformation Features (PDFs) and and the existence of diaplectic glasses of quartz and feldspar are also very good and quite conclusive evidence of a giant meteorite impact origin for the escorias. Although the escorias could be classified as impact-melt breccias, their unique characteristics may warrant a new term: "pampasitas", reflecting distinctive glasses created by melting of porous loess substrates. Source craters from most of these glasses have not been found so far but we must have in mind that impact craters in clay and loessoid deposits would have been rapidly destroyed by the erosion processes. By the published information (Schultz *et al* 1998, Zárate and Schultz 2002, Schultz *et al*. 2004 a and b, Zárate *et al.* 2004, Schultz *et al.* 2006) several impact event layers are well identified in the area. Radiometric ages were obtained by high resolution 40Ar/39Ar dating.

The potential impact sites in the zone are:

I. Centinela del Mar (Necochea area): Layer A: age: 0.23 Ma. Layer B: age: 0.44 Ma.

II. Chapadmalal (Mar del Plata area): age: 3.30 Ma.

III. Pehuén Có (Bahía Blanca area): age: 5.33 Ma.

IV. Laguna Chasicó: glass layers yielded an age of 9.24 Ma.

Reported Impact craters/structures in the area:

a) La Dulce Impact crater, Buenos Aires Province (S 38º 14', W 59º 12')

Examination of remote sensing data led to the identification of a conspicuous circular structure near the village of La Dulce, Province of Buenos Aires, as a possible source impact crater for one of the above mentioned layers. The structure has 2.8 kilometers in diameter and it could be classified as a simple-type impact crater. A steep cliff-lined rim walls the La Dulce crater on its eastern and southern sides. There the rim rises from 25 to more than 40 meters above the interior floor and 10 to 20 meters above the exterior plain. Radar data show that the northern rim is a much-subdued, but nonetheless complete, arcuate structure. This structure has been modified by the near Quequén river. Available gravity data suggest that the La Dulce structure is associated with a negative circular gravity anomaly. Samples collected on the flanks of the crater rim showed carbonate lapilli, carbonate spherules, impact melt breccias, shock-deformed minerals including quartz, plagioclase and ilmenite and particles of lechatelierite. Those are conclusive evidence of the impact origin of the structure (Harris *et al.* 2007). Age for this crater has been estimated in 0.445 Ma so this crater could be associated to one of the impact layeres of Centinela del Mar area.

b) General San Martín Structure (S 38º 00', W 63º 18')

A possible impact structure has been reported near the town of General San Martín, close to the boundary between Buenos Aires and La Pampa provinces. It has 10.0 to 12.0 kilometers in diameter. Although unimpressive in satellite images, the General San Martín circular structure is unambiguous in radar data. Its relief is a significant regional anomaly. Aerial examination confirmed that the structure has a raised rim that creates a broad topographic rise distinct from the numerous other lakes and salt pans in the area. Ground observations show that the rim of this structure is composed of highly fractured carbonate-cemented loess in places covered by carbonate breccias similar to some of the deposits surrounding La Dulce Crater. At present, direct evidence for an impact origin is lacking. A glassy mass was unearthed only a few kilometers from the structure and its age was estimated in 1.2 Ma (Harris *et al.* 2007). No escorias/tierras cocidas layer has been associated to this possible impact structure.

Bolivia

The Republic of Bolivia has a total surface of 1,098,581 square kilometers.

Only two possible impact craters/structures has been reported for Bolivia:

1) Iturralde Structure, also known as Araona crater (S 12º 35', W 67º 38') Figure 6.

This structure, a possible complex one of the central peak type, was discovered in 1985 from Landsat satellite images and it is located at the Amazonian lowlands in northwestern of the country. The structure is superimposed on alluvial deposits that accumulated over a vast area of SW Amazonia in late Quaternary times. Landsat images reveal a circular structure, about 8 kilometers in diameter, with a slightly elevated rim, with minor radial drainage and a shallow interior. An irregular rised area, about 2.0 x 3.0 kilometers, lies slightly off-center to the SE within the structure: that is a possible central uplift. Its estimated age is 30,000 to 10,000 years. So far, no *in situ* research has confirmed its impact origin. Access to this structure by surface is very difficult. If it is a real impact, it would be the youngest complex impact structure on Earth (Campbell *et al.* 1989).

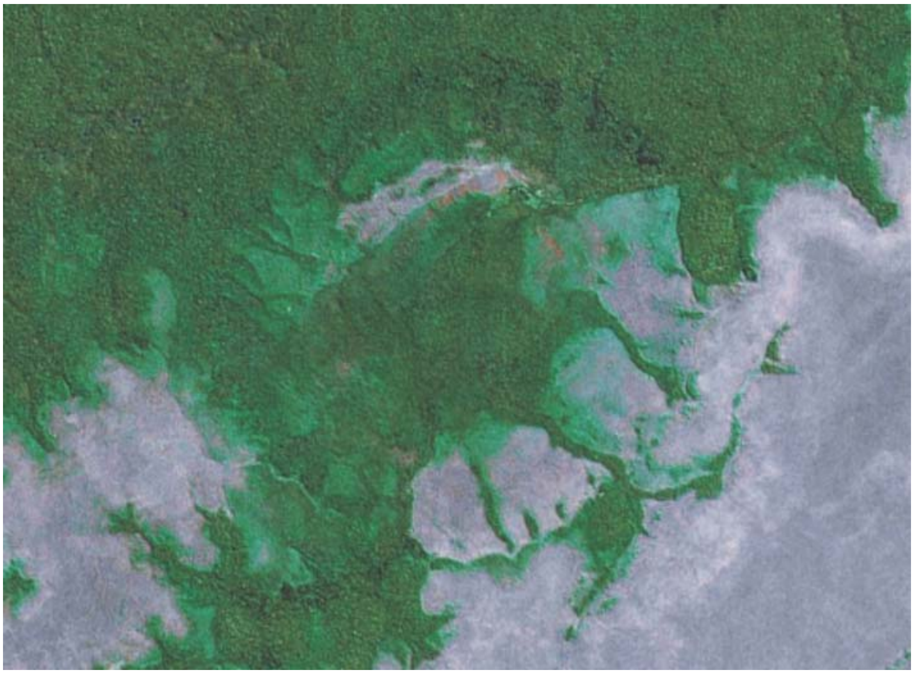

Figura 6 - Iturralde

2) Llica Structure (S 19º 49', W 68º 19') Figure 7.

The Llica crater is located to the NW edge of the Salar de Uyuni. It has an oval shape, 2.8 x 2.5 kilometers, elongated in the N-S direction. This bowl shaped structure, with a flat bottom and very steep inner walls, resembles a simple type impact crater. Integrated interpretation of the Landsat and SRTM images show that the crater has a raised external rim, probably formed by overturned strata of volcanic flows. The geological setting of this crater would suggest, at first glance, a volcanic origin since it is located among several volcanic cones of the Andean Cordillera. An examination of the digital elevation model for the region reveals that, contrary to all other volcanic craters in the region, this crater is located at a very distinct topographic low, right at the basin of a large volcano and surrounded by volcanic flows coming from the large volcano. No specific geological information about this crater was found and the region is very remote and of difficult access (Crosta 2004).

Brazil

The Republic of Brazil has a total surface of 8,456,508 square kilometers and it is the largest country in South America. There are at least three or four good review works about the brazilian impact craters e.g. Crosta 1987, De Cicco and Zucoloto 2002, Romano and Lana 2002 (in Spanish) and Romano and Crosta 2004. We are going to review the most important reported craters and structures for this nation:

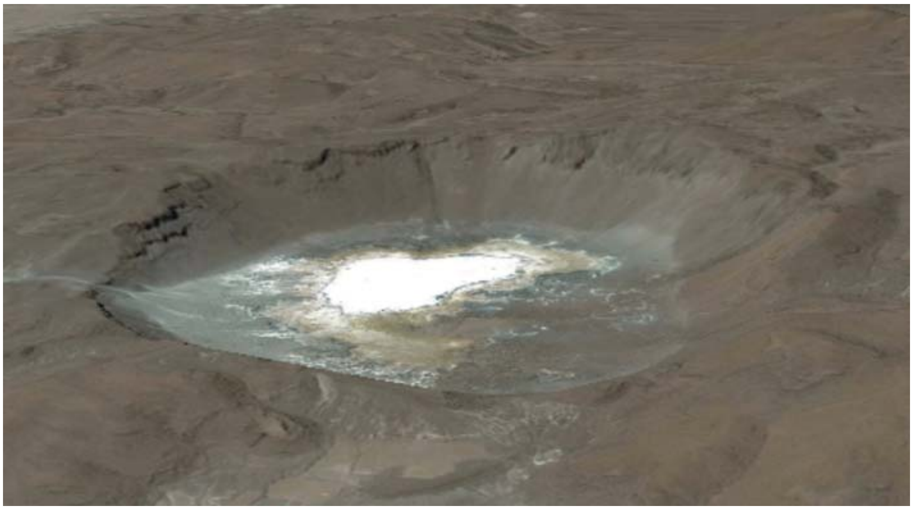

Figura 7 - Llica

1) Araguainha Dome (S 16º 46’, W 52º 59’) Figure 8.

This is so far the largest well stated impact crater in South America. Araguainha Dome is a 40-kilometer diameter circular structure in Paleozoic sediments of the Parana Basin. It shows a clear concentric and muli-ring aspect, a central uplift, raised rims and the whole structure is divided in the middle by the Araguaia River. The central uplift consists of a ring, about 8 kilometers in diameter, of up to 150 meters high blocks of Devonian sandstone, which surrounds a central depression of elliptical shape (4.5 x 3.0 kilometers). The depression is occupied by alkali-feldspar granite, shocked, and permeated by cataclastic shear zones and dikes of shocked granite. The target rocks directly affected by the impact structure are principally Paleozoic sedmients composed of siltstones, claystones and red sandstones. The structure is characterized by concentric zones of hills, inselbergs, and wall terraces that rise from the flat floor of the crater. This geomorphological pattern is largely controlled by the semi-circular grabens defined by a number of listric gravity faults dipping towards the centre of the structure. All of these characteristics are typical of complex impact structures that have a large diameter. The central uplift is predominantly composed of granitic rock in the core and intensely fractured red sandstones in the margins. The granitic rock, which may also occur as dikes, shows varied igneous textures, from fine- grained/glassy matrix with phenocrysts to coarse-grained hypidiomorphic texture. Intensely fractured sandstones surround the granitic core. Near the contact, these sandstones have their sedimentary bedding turned to the vertical due to ascent of the granitic rock in the uplifted core. The sandstones show abundant shatter cones (from centimeters to meters in size) as well as PDFs in quartz grains which are diagnostic of shock metamorphism. Polymict breccias occur as lenses in the central uplift, generally along the contact between the granitic core and the fractured sandstones. They also occur locally outside the central uplift. Araguainha is an eroded complex impact structure produced by an impact event 246 Ma ago. (Crosta *et al.* 1981, Theilen-Willige 1981, Theilen-Willige 1982, Martinez *et al.* 1991, Engelhardt *et al.* 1992, Hammerschmidt and Engelhardt 1997, Masero *et al.* 1997, Hippertt and Lana 1998)

2) Serra da Cangalha (S 8º 05’, W 46º 51’) Figure 9.

The Serra da Cangalha structure consists of a serie of concentric rings that are delineated by circular faults and by a semi-circular rim. Its total diameter has been estimated in 12 kilometers. It is located in Paleozoic sediments in the Parnaíba Basin. Its most remarkable feature is the 5.0 kilometer-wide ring-shaped range of mountains in sandstones of the Poti formation that make up the core. A perfect circle 250 meters high surrounds a valley at the center. This structure represents the resistant portion of a central uplift, which has been eroded. Shatter cones in its uplift beds of sandstones (Permian/Carboniferous) and breccia including Planar Deformation Features (PDFs) in quartz grains were found in this structure. Age has been estimated in less than 300 Ma. (Dietz and French 1973, Crosta 1987, Romano and Crosta, 2004, Adepelumi *et al.* 2005a y b, Reimold *et al.* 2006).

Figura 8 - Araguainha (Photo by The Canadian group at the Dominion Observatory)

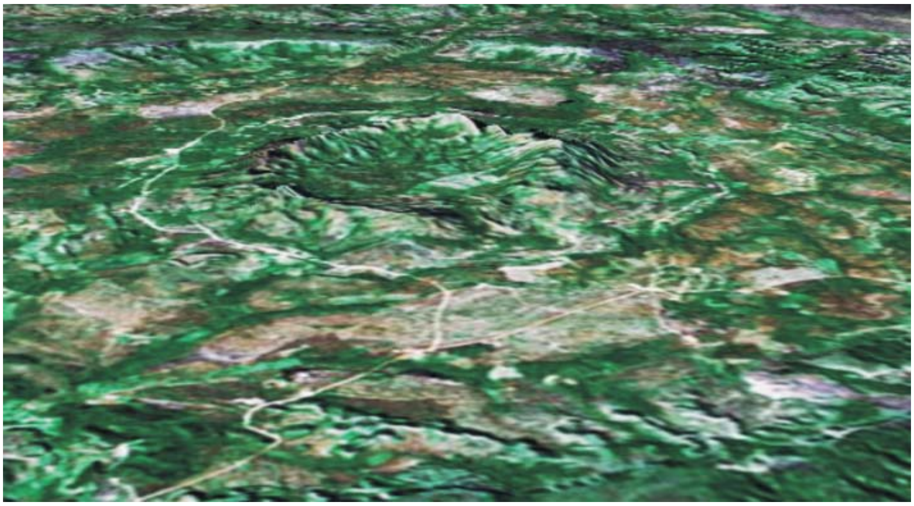

Figura 9 - Cangalha. (North behind the scene).

3) Gilbues or Santa Marta Structure, Piahui (S 10º 10', W 45º 14') Figure 10.

The Gilbues structure (also known as the Santa Marta Structure) is a 10-kilometers diameter circular structure which has a slightly oval shape. On Landsat MSS satellite images it is well defined by its prominent outer ring of rocks with positive relief best development in the South and Northeast. A thick, vegetated central region, still apparently covered, is surrounded concentrically by a sparcely vegetated annular ring, followed by the thick, vegetated outer rim. The structure is traversed by prominent northeast and north-northeast-trending fractures that cross but do not offset the rim. The structure is developed in Carboniferous sedimentary country rocks of Poti and Piahui Formations. The Gilbues structure is proposed as a possible Late Paleozoic to Mesozoic impact structure (Master and Heymann 2000, Romano and Crosta 2004).

4) Sao Miguel do Tapuio Structure (S 5º 38', W 41º 24') Figure 11.

This structure is located in the northern portion of the Piaui State and has around 20 kilometers in diameter. It is located on sedimentary rocks of the Paranaiba Basin. The circular structure of Sao Miguel do Tapuio has been cited as the product of an igneous intrusion (structural dome) not yet outcropping and so far there is, unfortunatelly, no conclusive evidence for an impact origen. It consists in assimetric scarps, concentric rings with a central uplift. Since there occur many other igneous basic intrusions with variable thickness on the region as well as a lack of sufficient evidence of impact shock metamorphism, it is premature to say that this circular structure is an impact crater. There has been some unconfirmed reports of shatter cones and Planar Deformation Features (PDFs) in grains of quartz. Age has been estimated in less than 120 Ma. (MacDonald *et al.* 2005).

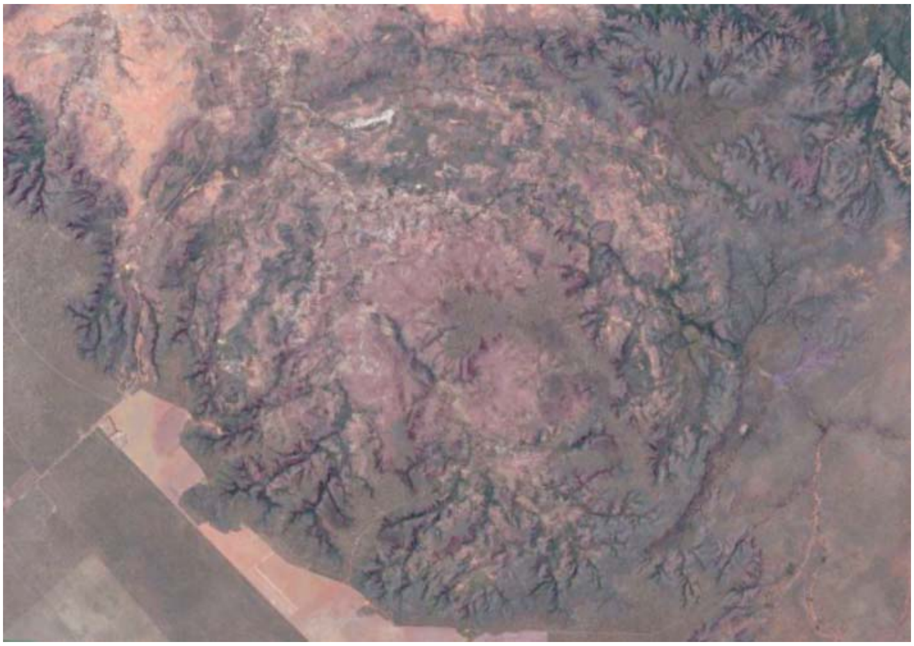

Figura 10 - Gilbues or Santa Marta. (North on the left)

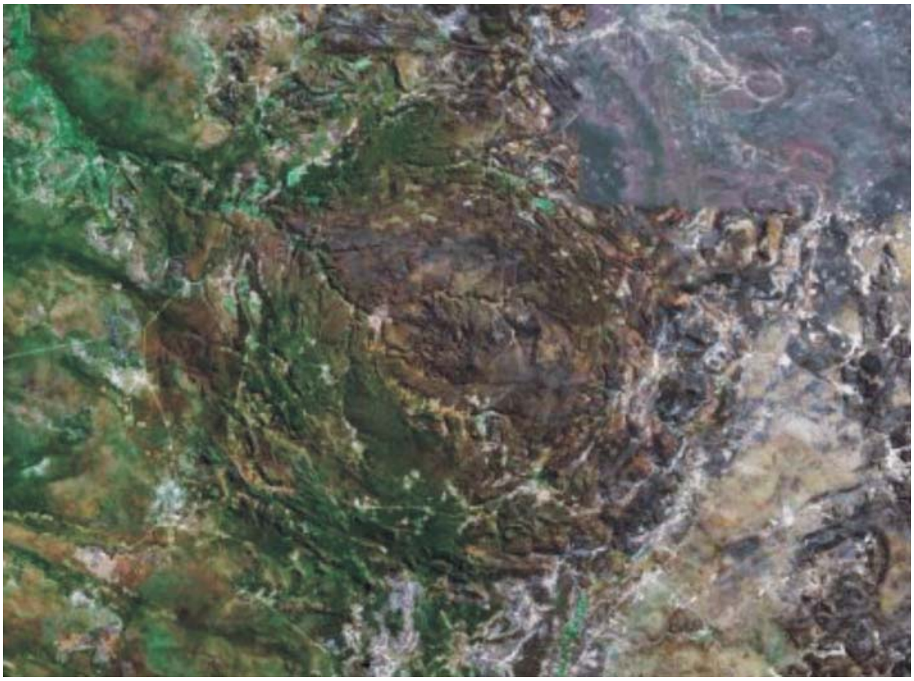

Figura 11 - Sao Miguel do Tapuio

5) Vergeao Dome Structure (S 26º 50’, W 52º 10’) Figure 12.

Vergeao Dome is a 12.4 kilometer-diameter circular depression located on Cretaceous basalts and Jurassic/ Triassic sandstones of the Sao Bento Group of Paraná Basin. It is a circular depression with a central uplift and it has a ring depression around the uplift. It is very evident because of its arrangement of circular, concentric fractures. Outside the structure, there are no occurrences of Jurassic/Triassic sandstones at the surface. Boreholes drilled for oil in the region found these sandstones at depths from 700 to 1000 meters. However, in the central uplift of the structure highly deformed blocks of sandstones crop out, bounded by faults. Uplift in the center of the structure seems to have reached some hundreds of meters, as indicated by the current position of the sandstones. Impact breccias found in the Vergeao Dome include monomict breccias of diabase and basalt and polimict breccias with fragments of sandstones, basalts, diabases and mudstone. There are also huge outcrops of breccias. Most of those breccias occur in concentric plateaux in the inner portion of the structure within and around its central uplift. Shatter cones and Planar Deformation Features (PDFs) in quartz and plagiocalse confirmed the impact origin of this structure. Age has been estimated in 117 Ma. (Kazzu-Vieira *et al.* 2004, Crosta *et al.* 2005).

6) Cerro Jarau Structure (S 30º 12’, W 56º 33’) Figure 13.

This possible impact structure consists of a circular feature of 5.5 kilometers. It has a central uplift and an annular graben. It is located next to Uruguay border on Mesozoic basalts and sandstones of the Paraná Basin. Its age has been estimated in 117 Ma. (de Cicco and Zucoloto 2002, Romano and Crosta 2004).

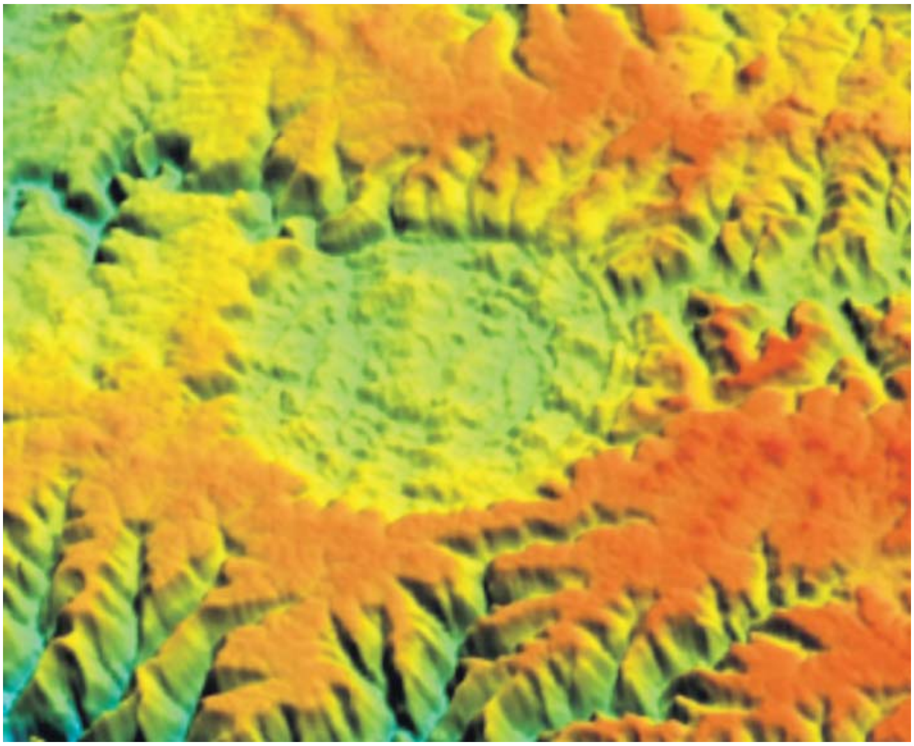

Figura 12 - Vergeao. (topographic image made from SRTM (radar) data (NASA) The Planetary and Space Science Centre

7) Vista Alegre, Paraná (S 25º 57’, W 52º 41’) Figure 14.

The Vista Alegre crater is a 9.5 kilometer-wide circular structure in the Paraná State, and it is located on the Cretaceous basalts of the Serra Geral formation. It has a very similar geological setting to that of Vergeao crater. Vista Alegre is an almost-perfect circular depression with steep borders and topographic gradients up to 300 meters. A central uplift appears as a subtle topographic feature represented by gentle hills. Polymictic basaltic impact breccias occur at the central portion of the crater. Boulders and sandstone with cataclastic deformation were found near the center. Planar Deformation Features (PDFs) were found in isolated quartz grains within the breccias together with cm.-size shatter cones formed in fine-grained material (Crosta *et al.* 2004).

Figura 13 - Jarau

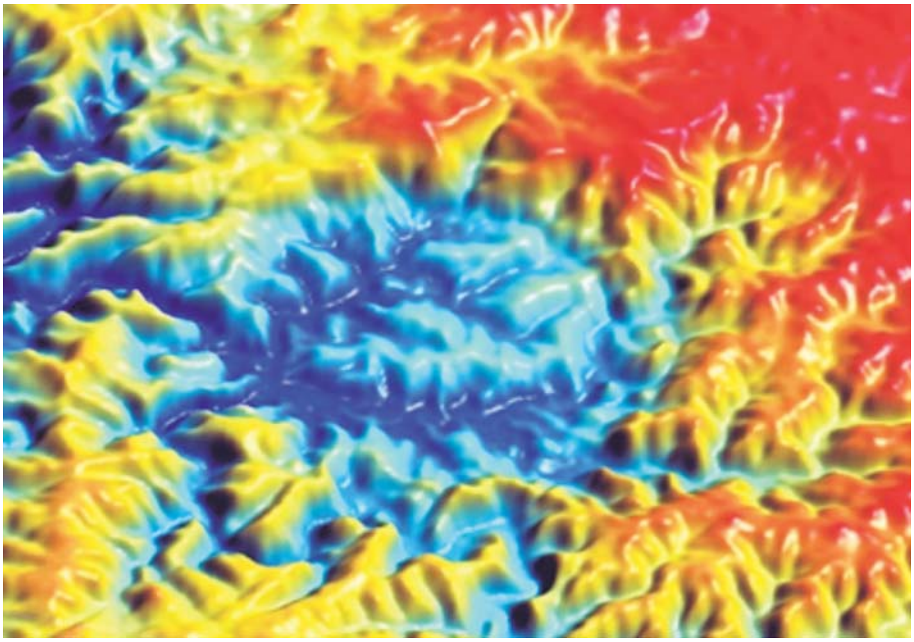

Figura 14 - Vista Alegre. (topographic image made from SRTM (radar) data (NASA) The Planetary and Space Science Centre

8) Inajah Structure (S 8º 40', W 51º 00') Figure 15.

It is anorther possible impact structure and needs more research to be confirmed or rejected. It consists in a weathered circular feature, of 6.0 kilometers in diameter, surrounded by a low elevated ring. The central portion is a depressed circular basin. Its age remains unknown (de Cicco and Zucoloto 2002, Romano and Crosta 2004).

9) Riachao Ring (S 7º 42', W 46º 38')

The Riachao structure is located in the southern portion of Maranhao State and it has a 4.0 kilometer diameter in sedimentary rocks of the Paranaiba Basin. It consists in a circular bleached area with a low relief and a central slighty elevated ring of eroded sandstones. It was first discovered by the members of an Apollo mission in 1975 (McHone 1979). Apparently, by the results of field works, the Riachao Ring involves only sandstones from the Pedra de Fogo Formation (McHone and Dietz 1978, McHone 1979). There is a central uplift and and outer graben, with both radial and concentric faults. Those authors have identified some evidence of one impact phenomena, such as the occurrence of shatter cones, polymict breccias inside the structure which were not detected in any of the stratigraphic wells done for hydrocarbon prospection in the region, as well as the uncommon pattern of microfractures in quartz grains observed in thin sections of polymict breccias. Its age has been estimated in less than 200 Ma. (Crosta 1987, Romano and Crosta 2004).

10) Piratininga Structure (S 22º 28', W 49º 09')

Piratininga structure (12.0 kilometers in diameter) has a circular shape and a central uplift. This possible impact crater is located on Mesozoic basalts and sandstones of the Paraná Basin (Romano and Crosta 2004).

11) Colônia Structure (S 23º 52', W 46º 42')

It is a possible impact structure and more research is needed to confirm or reject it as a real impact site. The Colonia structure is very evident and an almost perfectly circular basin. It has a total diameter of 3.6 kilometers. The structure itself it is located in crystalline rocks of the Precambric basement. It is filled by Quaternary clay sediments that make impossible a good prospection. Age has been estimated at arround 36 Ma. (Crosta 1987, Riccomini and Turcq 2004, Romano and Crosta 2004).

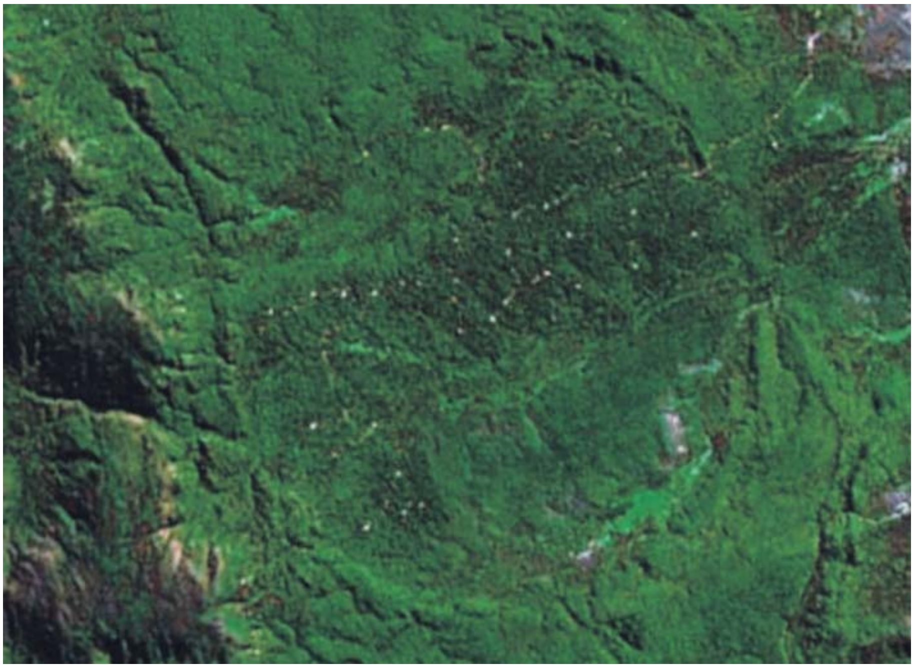

Figura 15 - Inajah

Colombia

The Republic of Colombia in South America has a total surface of 1,138,914 square kilometers and so far only one possible new meteorite impact site has been reported in this Latin-American nation. The geology of Colombia is dominated by the Tertiary-Quaternary mountains, volcanoes and ridges of the Andes in the West and by the tropical sedimentary basins in the East.

Only one but very large possible impact strcuture has been reported for this nation:

1) Río Vichada Structure, Comisaría Vichada (N 4º 30', W 69º 15') Figure 16.

The Río Vichada Structure has a diameter of 50 kilometers and it is the largest possible impact structure ever reported in the continental South America. This area is part of the Llanos Basin and it is covered of tropical rainforest. The structure has the typical multi-ring shape configuration of large impact structures with a central peak. The central core consists of a ring about 30 km. in diameter which surrounds a central depression of circular shape and 20 km. in diameter. In this innermost region, there is a basin, the relief is quite smooth and it is the deepest part of the structure. The central basin is covered by jungle and it is surrounded by 2 concentric rings of low hills (no more than 200 meters high each). The outermost ring has 50 km in diameter and in the South, the Vichada River flows around it in a perfect semi-circle following the external limits of this outer ring of hills. This flow around feature of the river is very interesting and anomalous. Rocks exposed in the Río Vichada structure include Precambrian meta-sedimentary and granitic rocks with an extensive sedimentary cover. The sedimentary cover is composed by a heterogeneous sequence of conglomerates, sandstones and clays. They are dated Tertiary and they cover the Precambric crystalline basement rocks. The circular structure has its roots in the Precambric crystalline granitic basement (Rocca 2004c). At present it is dangerous to go to the field because the area is not under the control of the government forces. However, recently, a team of local colombian geologists from Universidad Nacional de Colombia have performed an approach. They have studied in detail the geophysical characteristics of the structure. They found both a gravity and a magnetic circular anomalies associated to the exact site of the circular structure visible in satellite images. They found that their characteristics match perfectly those of a giant multi-ring impact crater (Hernandez *et al.* 2007, Khurama 2007, Hernandez and von Frase 2008). Petrographic studies of samples collected in the area are in progress.

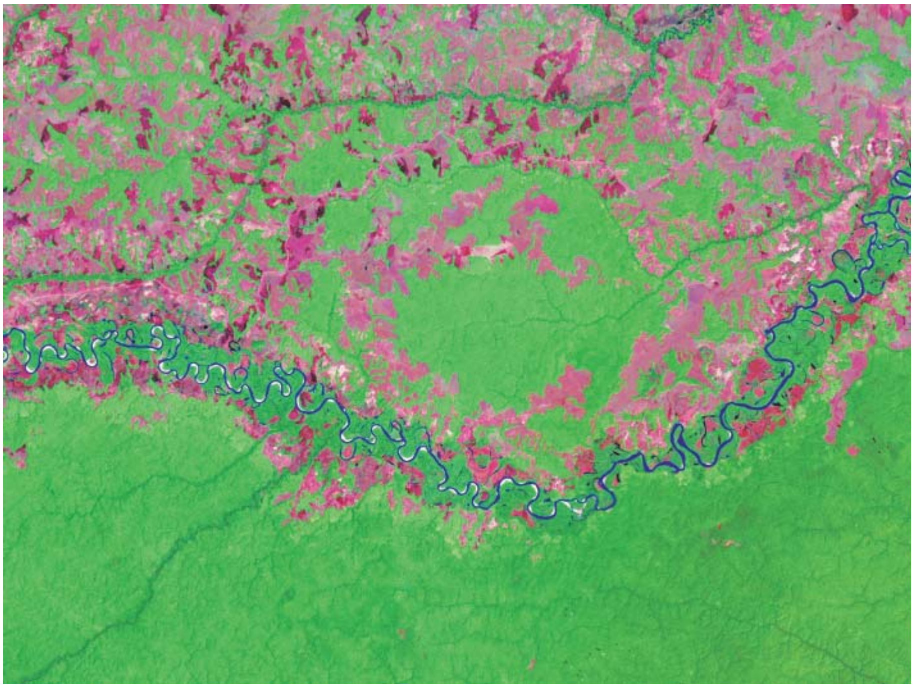

Figura 16 - RÃo Vichada

Chile

The Republic of Chile has a total surface of 736,793 square kilometers and its geology is dominated by the Tertiary-Quaternary Andean Ridges.

At present there is only one impact crater reported for this nation:

1) Monturaqui (S 23º 56', W 68º 17')

The Monturaqui impact crater, Atacama, is a simple-type impact crater and was discovered in 1962 by examination of aerial photographs. Later, geologic research confirmed its meteoritic impact origin. Diameter is 460 meters, depth, 31 meters. It has a raised rim. The crater lies in an area of desert hills of the Monturaqui range and it is located in the high Atacama Desert (altitude of 3500 meters). The Monturaqui crater is emplaced in Jurassic granite rock, overlain by a thin Tertiary-Quaternary ignimbrite sheet. The impacting asteroid was metallic: an Iron-Nickel object. Meteorite specimens have not been recovered, but, meteoritic iron shale was found on the outer rim of the crater and highly vesicular impact glass material was abundont on the South and SE flanks of the crater. The impactites have shocked minerals and rock fragments as well as tiny Fe-Ni-Co-P sherules, all bound in glass. Analysis of the mixed matrix glasses indicated extreme compositional differences compared to granite country rock. Glass shows enrichment in Fe, Ni and Co. These metallic elements came from the impacting metallic asteroid no doubt. The age of this crater has been estimated in about 1 Ma (Sanchez and Cassidy 1966, Bunch and Cassidy 1972).

Perú

The Republic of Peru has a total surface of 1.285.215 square kilometers. Its geology is dominated by the Andes Cordillera.

The following is the only impact crater so far reported for this nation:

1) Carancas (S 16° 40', W 69° 02') Figure 17.

On September 15, 2007 at 11.45 Hours (local Time) a H4-5 type ordinary chondrite meteorite crashed in Perú near the village of Carancas leaving a simple type impact crater with a diameter of about 15 meters into channel and bank depossits of a narrow arroyo. It is the first meteorite impact event ever recorded in the XXI Century. A local official, Marco Limache, said that "boiling water started coming out of the crater, and particles of rock and cinders were found nearby", as "fetid, noxious" gases spewed from the crater. The crater size was given as 13.80 by 13.30 meters, with its greatest dimensions in an east-west direction. The fireball had been observed by the locals as strongly luminous with a smoky tail, and seen from just 1000 meters above the ground. The object moved in a direction toward N030E. The strong explosion at impact shattered the windows of the local health center 1 kilometer away. A smoke column was formed at the site that lasted several minutes, and boiling water was seen in the crater. The official classification of the Carancas meteorite was done by a team of scientist working at the University of Arizona. The meteorite is an H4-5 type ordinary chondrite. Ejecta blocks ranging from tens of centimeters to approximately one meter across are observed extending several meters from the rim around most of the crater, although possible zones of avoidance may be present to the N and ESE. Blocks derived from beneath the arroyo, clustered outside the S to SE rim, are observed in a variety of orientations from top-up to completely overturned. Beyond the WNW to NW rim the largest blocks are overturned and resting in a blanket of extremely fine, powdery material up to approximately 50 cm. thick. It seems that the space object of the Carancas impact event (a meteoroid of about 1 meter in diameter) entered into the Earth's atmosphere in a very special angle that allowed it to reach the ground and impact (Harris *et al.* 2008, Schultz *et al*. 2008). Usually meteoroids of that size never reach the ground and burns in the Earth's atmosphere. So the Carancas impact event was a very unusual case.

Figura 17 - Carancas. (Photo by Randall Gregory)

Uruguay

The Republic of Uruguay has a total surface of 177,508 square kilometers.

So far no possitive impact crater or structure has been reported for this nation. However there has been one report of possible impact glasses:

1) Possible impact glasses from the Atlantic coast of Uruguay and Southern Brazil Figure 18.

There have been reports of possible meteorite impact glasses from the Atlantic coast of Eastern Uruguay and the South of Brazil. Those glasses appear in very large quantities at the Atlantic coast of La Paloma, La Pedrera, Cabo Polonio and Punta del Diablo areas. That area represents more than 150.0 kilometers of coast.

Figura 18 - Uruguayan scoria

They can be classified in two types:

A-Scoriaceous masses of glass with a rough pitted surface. They are gray-brown in color. Inside they show a brecciated structure: fragments of a tufa-like white glass sandstone included in a green-brown mass of glass full of bubbles of different sizes.The inner surface of the bubbles has a gleam of a green-brown color. The biggest specimens could weigh more than 1 kilogram.

B-Bomb like pieces: made up inside a very cellular white snow glass, like volcanic pumice stone. The outside surface of the bombs consists of a brown-gray glass cover free of bubbles. Inside they are cellular showing hundreds of small bubbles (Rocca 2001). These glasses are present both onshore and offshore in the above mentioned area. They have been also found in large quantities underwater, quite far away from the shore line of the coast. The geology of the involved area is dominated by the Precambric crystalline basement of acid rocks. There are also many areas covered by dunes and some local depossits of clays of Quaternary-Recent age. The glasses were, in some cases, found enclosed in the Quaternary-Recent clay depossits in farms on the land and, again, far away from the coast of the ocean. Their age can be estimated as Quaternary or even Recent. The origin of these glasses remains a mystery. They could really be meteorite impact distal or proximal ejecta and they could perhaps be also man made (perhaps smelting industrial waste used as ballast by steam boats). Their huge quntities is very impressive. These glasses remain a mystery and they demand more research.

Conclusion

At present the numbers of impact craters in the countries of South America are the following:

Argentina: 14.

Bolivia: 2.

Brazil: 11.

Colombia: 1.

Chile: 1.

Ecuador: 0.

Guyanas: 0.

Paraguay: 0.

Perú: 1.

Uruguay: 1

Venezuela: 0.

More searches no doubt will discover new examples of impact structures in these countries.

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