Chapter 2
Argentina

The República Argentina has a total surface of approximately 2.8 million km^2.

So far, there is only one review paper devoted to the Argentinian impact craters (Acevedo and Rocca 2005).

This chapter contains possible and confirmed cases of this country and a number of new previously unknown proposed sites shown in Fig. 2.1.

2.1 The Campo del Cielo (27° 30′ S, 61° 42′ W)

The Campo del Cielo meteorite field (Fig. 2.2) is composed, 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 a large amount of meteorite specimens survived the impact. The diameter of the impactor has been estimated about 10 m (Liberman et al. 2002). The provenance of the impactor was from the SW and entered into the Earth's atmosphere at a low angle of about 9°. As a consequence, the asteroid broke into 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 Spanish colonial times (sixteenth to nineteenth centuries). Craters and meteorite fragments are widespread along an oval area of 18.5 × 3 km (SW–NE), thus making Campo del Cielo as one of the largest meteorite crater fields known in the world (Cassidy 1967, 1968, 1971; Cassidy and Renard 1996; Cassidy et al. 1965). The craters show raised rims and overturned 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 1–4 are probably explosion craters. These four craters differ from the others in that (a) they are deeper and/or have greater original depth/diameter ratios, (b) they have a more circular shape as opposed to the elongated nature of the other 16, (c) they do not have large magnetic anomalies associated, and (d) they have numerous meteorite fragments of the disrupted impacted asteroid within the ejecta blanket (Wright et al. 2006, 2007; Vesconi et al. 2011).

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Fig. 2.1 Geographical location of some proven and possible impact craters in Argentina

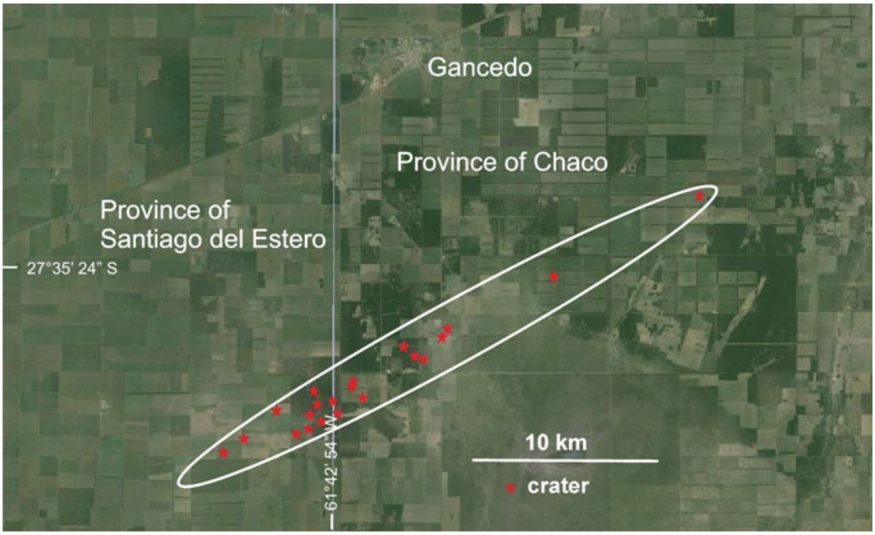

Fig. 2.2 Campo del Cielo. *Credit* © 2013 Inav/Geosistemas SRL, © 2014 Cnes/Spot Image, Image © 2014 DigitalGlobe

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

(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 dimension is 105 m from rim to rim. A shallow gully found in the rim gives it its name. The crater is presently 2 m deep at its deepest.

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

(3) This structure is called "Laguna Negra" due to the dark-colored water lake that filled it. It is the largest impact crater of the strewn field with a diameter of 115 m. It is quite shallow, only 2 m deep at its center. It is undoubtedly an explosion crater and not a penetration funnel as most of the other craters in the same strewn field.

(4) This crater is about 85 m in diameter and 1.5 m deep.

(5) This crater is shallow and with an ill-defined rim. It is about 45 m in diameter.

(6) These twin craters share a common east–west rim. The larger has a diameter of 35 m, while the smaller is 20 m across.

(7) This crater is elliptical in outline with rim-to-rim dimensions of 96 × 74 m.
(8) This is also an elliptical penetration funnel with a size of 46 × 28 m.
(9) Inside this crater, there is also a penetration funnel, named as "La Perdida," where several meteorite pieces were discovered weighing in total about 5,200 kg.
(10) This crater is called "Gómez," with a diameter about 25 m. 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 on Earth.
(11) This is a small crater and its rims are not very well defined. It is a penetration funnel and not an explosion crater. A huge meteorite specimen with a weight of 14,850 kg was found inside it (Wright et al. 2006).
(12) This is also a penetration funnel and not an explosion crater. A large meteorite specimen with a weight of 7,850 kg was found here.

The craters of Campo del Cielo represent a site of unique characteristics on Earth and their study will continue still for many decades.

2.2 Bajada del Diablo (42° 48′ S, 67° 26′ W)

A very remarkable site of a new, quite large, meteorite impact crater field is present in this area. It was discovered in the 1980s (Corbella 1987). Approximately 200 small simple-type craters are widespread over an area of 35.2 × 17.6 km, that is roughly a total surface of 480 km^2, located in Central Patagonia (Rocca 2006; Acevedo et al. 2007, 2009, 2010, 2011a, b).

Most of these craters show clear evidence of having raised rims. Craters are mainly located on areas where fluvial sedimentary deposits (sandstones and conglomerates) of Pliocene–Early Pleistocene age are exposed (Fig. 2.3), but many craters are also located on several different geological terrains like, e.g., small Miocene basaltic plateaus and pyroclastic rocks. Areas exposing Late Pleistocene and Recent fluvial sediments show no craters, proving that the impact event took place sometime after the Early Pleistocene but before the Late Pleistocene. Undoubtedly, many craters have been erased by Holocene fluvial erosion processes and what we see today is just a fraction of the original population of craters. The original total number of impact craters, before the area was affected by erosion, has been estimated in about 550.

In situ geophysical research has showed significant gravimetric and magnetic anomalies associated to the craters. This is interpreted as a confirmation of the impact origin of these depressions.

Laboratory tests have shown nickel anomalies and lawrencite-bearing melt microspherules have been found into the ejecta blankets of some craters, but no meteorite fragments associated to the craters have been identified so far (Acevedo et al. 2012a).

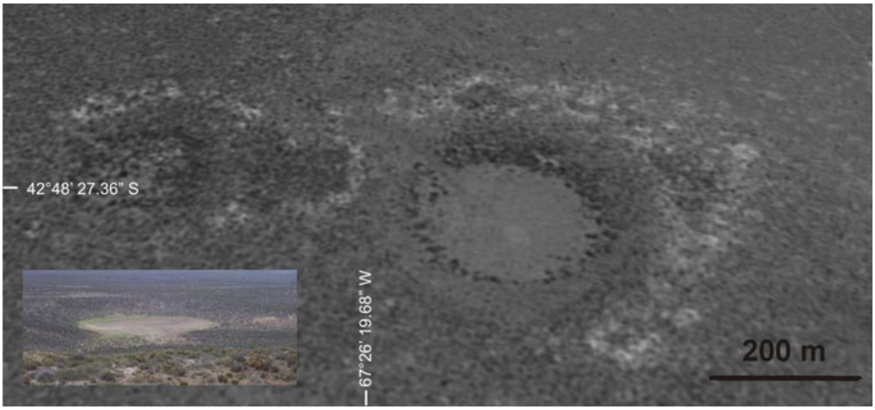

Fig. 2.3 Bajada del Diablo. *Credit* R.D. Acevedo, © 2013 Inav/Geosistemas SRL, © 2014 Cnes/Spot Image

New metallic and vitreous microspherules have been discovered into an impacted limestone of tuffaceous material that is located immediately underneath eolian sediments at the center of the "crater 8," 1.5 depth (Fig. 2.4).

The age of this impact is estimated approximately between 0.78 Ma (the end of the Early Pleistocene) and 0.13 Ma (the beginning of the Late Pleistocene) (Acevedo et al. 2009, 2010, 2011a, 2012a). When meteorite showers reach the ground, they expand into a strewn field which usually defines an elliptical-shaped area known as 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 yet visible in the images. Most probably, this craters field is the result of the impact of a 100–200 m wide cosmic object (a comet or an asteroid) which was broken in hundreds of fragments by the Earth's gravity force short before entering the atmosphere. Then, the swarm of fragments created the crater field. This site could be the largest meteorite impact crater field known on Earth. Further investigation of this interesting site is still in progress.

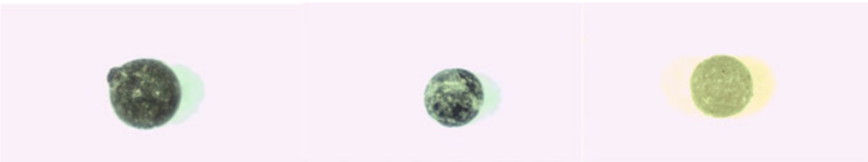

Fig. 2.4 Microspherules exhumed from impacted limestones. Diameters ~200 μm

Recent controversy about Bajada del Diablo crater-strewn field:
However, Reimold et al. (2014)—in a Letter to the Editor in Meteoritics and Planetary Science, related to judgmental errors about recognition criteria of impact craters—and Reimold and Koeberl (2014a, b)—in an article and one short note published both in the Journal of African Earth Sciences—rejected the relationship of the Bajada del Diablo impact crater-strewn field to any impact-cratering process since, in their opinion, Acevedo et al. (2009, 2012a, b, c among other papers) had not found direct evidence of it.

But beyond such hypercritical interventions, astonishingly, the cited authors tarnish the mention of noteworthy finding of Bajada del Diablo team research: the critique locality appears as the first known example in which the fragmented impactor collided against contiguous but different geological environments, leaving craters on each affected separate lithostratigraphic unit. These are the Miocene volcanites of the Quiñelaf Eruptive Complex and the Pliocene sedimentary rocks of the Pampa Sastre Formation (Fig. 2.5). Other strewn fields around the planet are carved over a unique stratigraphic column, respectively (just to provide a few examples: Sikhote Alin/Jurassic siliceous-clayey rocks; Campo del Cielo/Recent

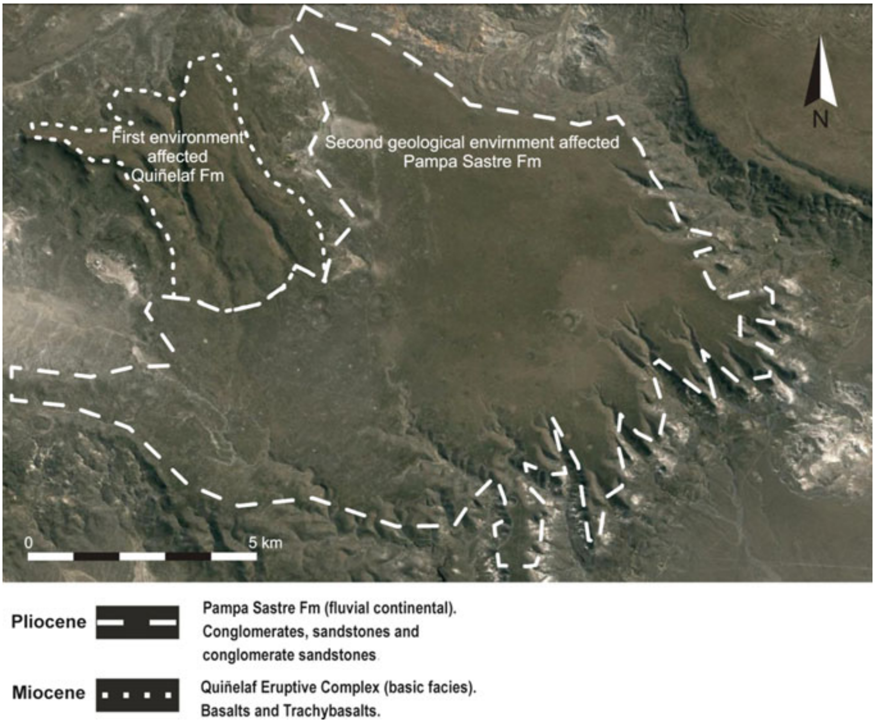

Fig. 2.5 Satellite image showing the two different, contiguous geological environments where impact craters are found (adapted from Acevedo et al. 2014c)

alluvial sands, clays and soils; Kaali Järv/Silurian sandstones and overlying Quaternary sediments; Henbury/shale and siltstone of Precambrian age; Morasko/deformed Neogene and Pleistocene deposits; Wabar/Recent dune sands; Macha/sedimentary rocks of Late Proterozoic age covered with Early Quaternary sands; Odessa/limestone and shale of Lower Cretaceous).

Obviously, this unique circumstance may apply only to impact crater-strewn fields; consequently, this new instance of impact identification is not envisioned, at least explicitly, within their own scheme of impact evidences (French and Koeberl 2010; Reimold and Koeberl 2014a).

Therefore, Acevedo et al. (2014a, 2015) suggest that this new impact recognition criterion for impact crater-strewn fields should be taken into consideration in the evaluation of this locality and other examples to be described in the future. This may be their most relevant contribution to this discussion.

2.3 Río Cuarto (32° 52′ S, 64° 13′ W)

First noticed by airplane pilot R. Lianza, the Río Cuarto craters are, at least, 11 oblong rimmed depressions ranging in size from “Crater A” of 4.5 × 1.1 km, 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 3–7 m above the surrounding plains. They are aligned in a parallel form in the NE–SW direction (Fig. 2.6) 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 of 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 m, 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 ground. The age of this 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 demonstrate that there are no truly raised rims but instead dune forms and no ejecta accumulation is present 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 aeolian origin (that is, deflation basins), rather than an impact origin for those elongated

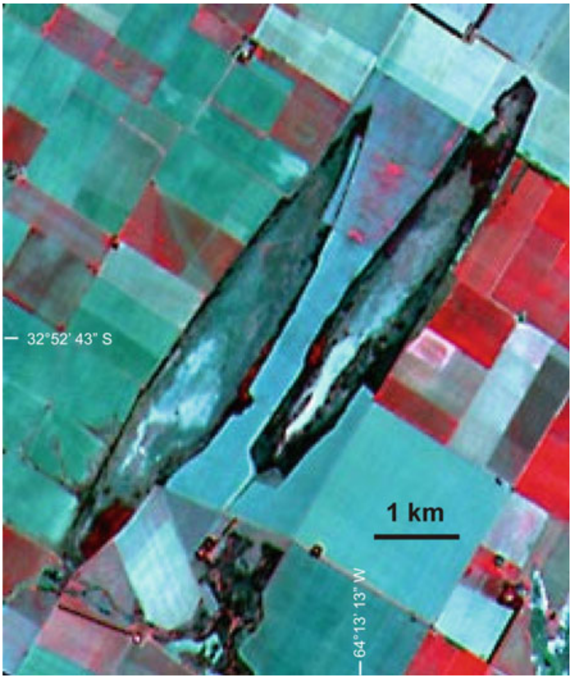

Fig. 2.6 Río Cuarto. *Credit* Image Landsat–NASA

depressions. There are nowadays doubts and controversy concerning the original hypothesis of an oblique impact in Río Cuarto. However, it is still possible that the glass found at the Río Cuarto structures is derived from an impact event. It may be distal rather than proximal ejecta. Age of the new glass samples found in the site was 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 (Schultz et al. 2004a, b). Anyway, source crater remains doubtful or unknown. The situation is so far very unclear and the area demands more detailed research.

2.4 Salar de Antofalla (26° 15′ S, 68° W)

A possible large simple-type impact crater of 750 m in diameter (Fig. 2.7) has been reported in the SE corner of the Salar de Antofalla (Fielding and Alonso 1988; Alonso and Fielding 1992). It was discovered through the examination of Landsat satellite imagery. It seems to be well preserved, although its rims are a bit eroded. It is placed on ignimbrite rocks of Cenozoic age. This crater demands in situ research to be confirmed as such.

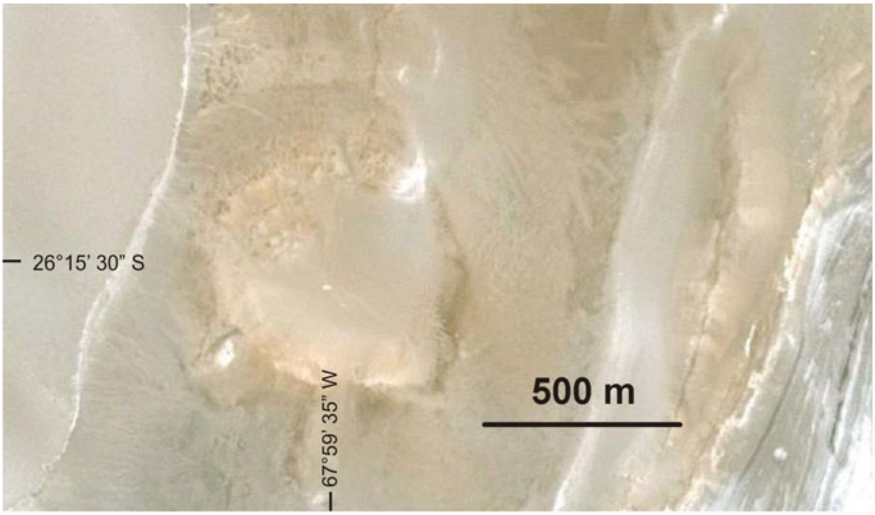

Fig. 2.7 Antofalla. *Credit* © 2012 Inav/Geosistemas SRL, © 2012 Cnes/Spot Image

2.5 Salar del Rincón (23° 58′ S, 67° 01′ W)

The geologist Esteban Tálamo discovered 5 small craters, of about 30–50 m in diameter, separated by around 220 m and located upon colluvial and alluvial Tertiary deposits at 3,800 m above sea level (Fig. 2.8). The age of the impact may be estimated as Holocene (Acevedo et al. 2014b).

2.6 Salar del Hombre Muerto (25° 12′ S, 66° 55′ W)

As part of an ongoing project to discover meteorite impacts, a potential new large meteorite impact crater field was found through careful examination of Landsat color images and aerial photographs (Rocca 2004b). Possible 10 small (with diameters from 90 to 250 m), fresh simple craters are located on a Quaternary alluvial cone of sedimentary deposits (Fig. 2.9). The diameter of the largest crater is 250 m. Craters are widespread in an oval area of 5 × 4.5 km. These craters seem not to be located on a tectonic fault. Most probably they may be collapse structures in the alluvial fan, or the result of a meteorite shower. Their age, whatever the event is, is very recent.

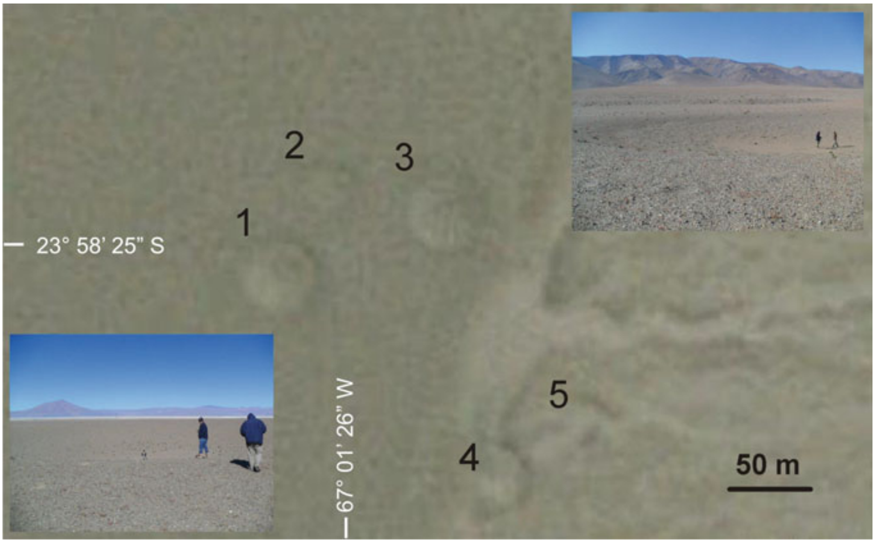

Fig. 2.8 Salar del Rincón. *Credit* Esteban Tálamo, © 2014 Cnes/Spot, Image © 2013 Inav/Geosistemas SRL

Fig. 2.9 Salar del Hombre Muerto. *Credit* © 2013 Inav/Geosistemas SRL, © 2014 Cnes/Spot, Image © 2014 DigitalGlobe

2.7 Salar de Arizaro (24° 55′ S, 67° 27′ W)

A possible new simple-type impact crater has been recently discovered in Salta Province, northern Argentina: the crater at Salar de Arizaro. It was discovered through the observation of satellite Landsat and Google Earth images and has 185 m in diameter (Fig. 2.10).

The crater feature is a bowl-shaped depression with a clear raised rim and a central depression. The crater interior is of a lighter shade and it seems to be filled by sand.

It looks very different from other depressions that are present in the area.

The local geology would agree with a meteorite impact origin. The area is mainly composed of evaporated salt deposits, sandstones, and gypsum of Tertiary–Quaternary age.

No volcanic features have been so far reported for this site. This crater is of Tertiary–Quaternary age.

Further investigation on this interesting crater is in progress (Acevedo et al. 2012c).

2.8 Sierra de Ambato (28° 03′ S, 66° 03′ W)

This crater was discovered from aerial observations by airplane pilot J.A. Viaña. It is almost 2 km in diameter (Fig. 2.11). It is a possible new simple-type impact crater. The crater feature is a clear ring with a raised rim and a central depression. The area all around the crater is full of radial and concentric fractures and faults. These faults

Fig. 2.10 Salar de Arizaro. © 2013 Inav/Geosistemas SRL, © 2014 Cnes/Spot Image

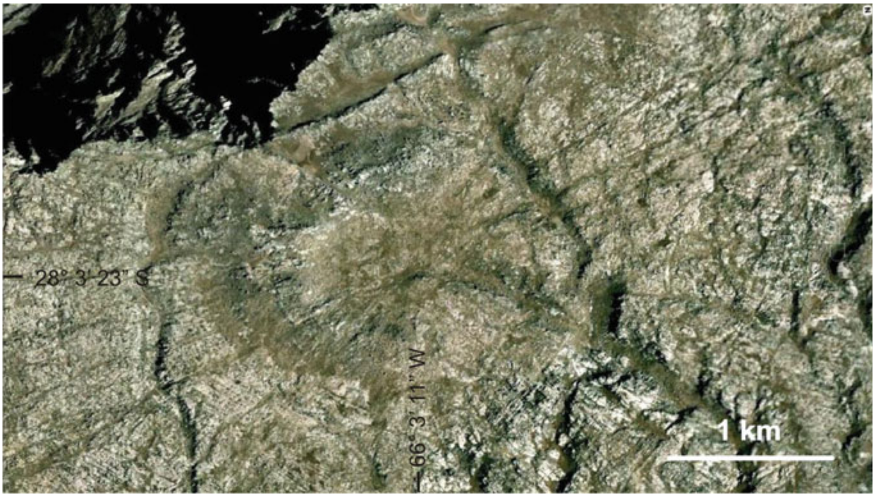

Fig. 2.11 Ambato. *Credit* © 2011 Inav/Geosistemas SRL, Image © 2011 DigitalGlobe, © 2011 Cnes/Spot Image

and fractures are typical of simple-type impact craters. The local geology is not in conflict with origin by a meteorite impact. The area is composed of metamorphic Precambrian–Cambrian rocks intruded by Paleozoic granitic rocks. The crater has been a bit flattened by erosion. No volcanic rocks or features have been so far reported for this site. This crater is probably a largely eroded, simple-type meteorite impact crater. Alternatively, the site may be related to plutonic processes. Its age is estimated as Paleozoic based upon geological and structural evidence. Further investigation of this interesting crater is also in progress (Acevedo et al. 2012b).

2.9 Cuesta de Miranda (29° 25′ S, 67° 40′ W)

This is a sub-circular structure of 300 m in diameter (Fig. 2.12). It is located in the mountains of the Famatina System at 2,725 m above sea level. It is a clear depression with raised rims imprinted upon Devonian granitoid rocks.

2.10 Structures Which May Not Be Impact Craters

2.10.1 Tonono (22° 16′ S, 63° 28′ W)

This structure is a sub-circular ring showing a diameter of 2 km and 8 m depth in the Salta rain forest (Fig. 2.13). The local geology is composed of sedimentary rocks of the Tonono Formation (Silurian–Devonian).

Fig. 2.12 Cuesta de Miranda. *Credit* Image © 2014 DigitalGlobe, © 2013 Inav/Geosistemas SRL

Fig. 2.13 Tonono. *Credit* Image © 2014 DigitalGlobe

2.10.2 *Las Garzas (28° 43′ S, 59° 29′ W)*

This is a circular feature of 1.9 km in diameter and 3 m in depth (Fig. 2.14). It shows a large, central wet area. It is located on Quaternary sediments of the Chaco-Paranaense basin.

2.10.3 *Alicurá (40° 35′ S, 70° 54′ W)*

This structure has been cut by erosion of the Río Limay (Fig. 2.15). It is 1.2 km in diameter and 95 m in depth and it looks as a slump on the Alicurá Formation, which is composed of sands and gravels of Early Pleistocene age.

2.10.4 *Los Mellizos (47° 20′ S, 70° W)*

The Los Mellizos structure is a large circular depression in the Deseado Massif, a hilly cratonic plateau in northeastern Santa Cruz Province, southern Patagonia. The crater forms a circular basin with a rim-to-rim estimated diameter of 12 km (Fig. 2.16). The rim consists of a circular ring of low hills. This circular feature has

Fig. 2.14 Las Garzas. *Credit* Image © 2014 DigitalGlobe, © 2014 Cnes/Spot Image

Fig. 2.15 Alicurá. *Credit* Image © 2014 DigitalGlobe, © 2014 Cnes/Spot Image

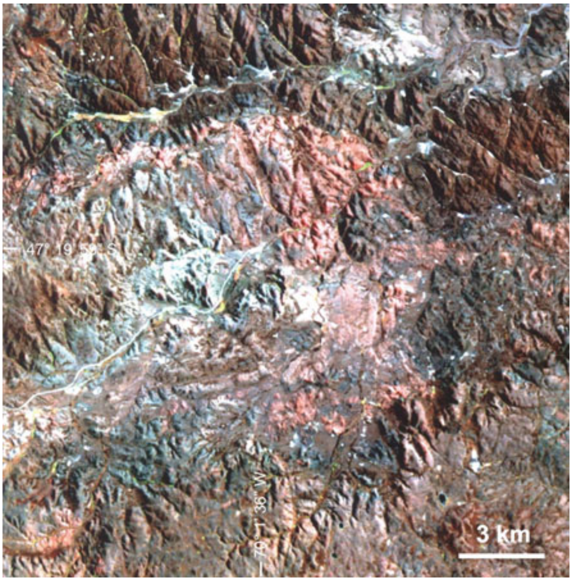

Fig. 2.16 Los Mellizos. *Credit* Instituto Geográfico Militar

also a clear difference in its color (light orange to pinkish) when compared to the color of the surrounding area (brownish). 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. To the north, a small river flows around the circular rim of the structure and another small river crosses the whole structure from SW to NE. A central peak is apparently exposed and it is visible in the radar images of the German DLR X-SAR. At present, the geology of this entire area is still unknown in detail. The surroundings of the structure are made up of volcanic formations of Middle Jurassic age (170–140 Ma), the Chon Aike Formation. Rocks exposed there are rhyolitic ignimbrites, pyroclastic rocks, and tuffs. This structure is quite old and deeply eroded and it could represent a new example of an impact structure formed on siliceous volcanics or, alternatively, the site may be of igneous origin. This could be the largest impact structure of mainland Argentina (Rocca 2003a, b, 2007).

2.10.5 Santa María (26° 44′ S, 66° W)

A possible new simple-type impact crater has been reported for the Valle de Santa María, in the province of Catamarca, northwestern Argentina. It was studied through the examination of Landsat satellite images and aerial photos. The possible crater has a diameter of 1 km; it has raised rims and it seems to be partially eroded (Fig. 2.17). It is located in a remote desertic area, on sandstones of the Andalgalá Formation, which has been dated as Miocene–Pliocene in age (Gavriloff 2008).

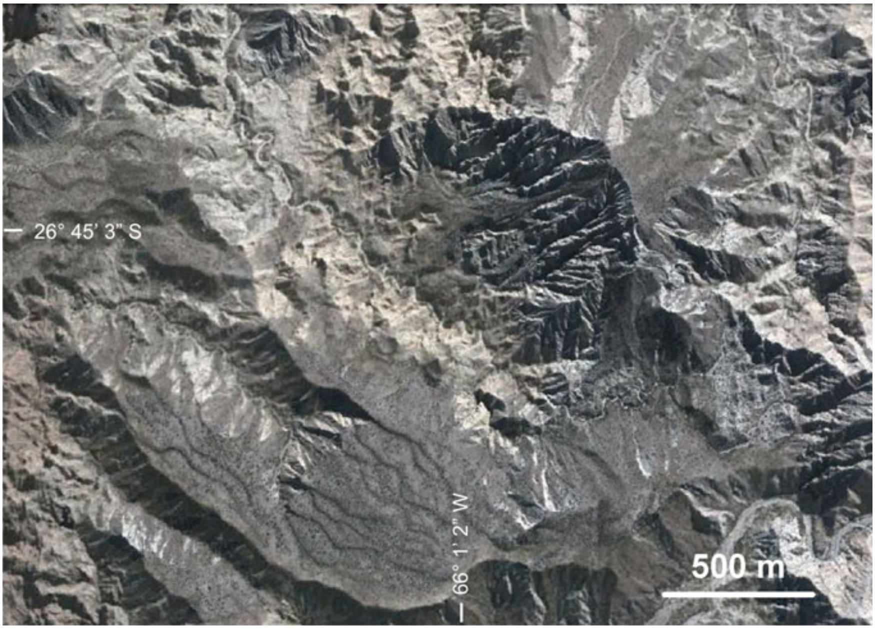

Fig. 2.17 Santa María. *Credit* Image © 2014 DigitalGlobe

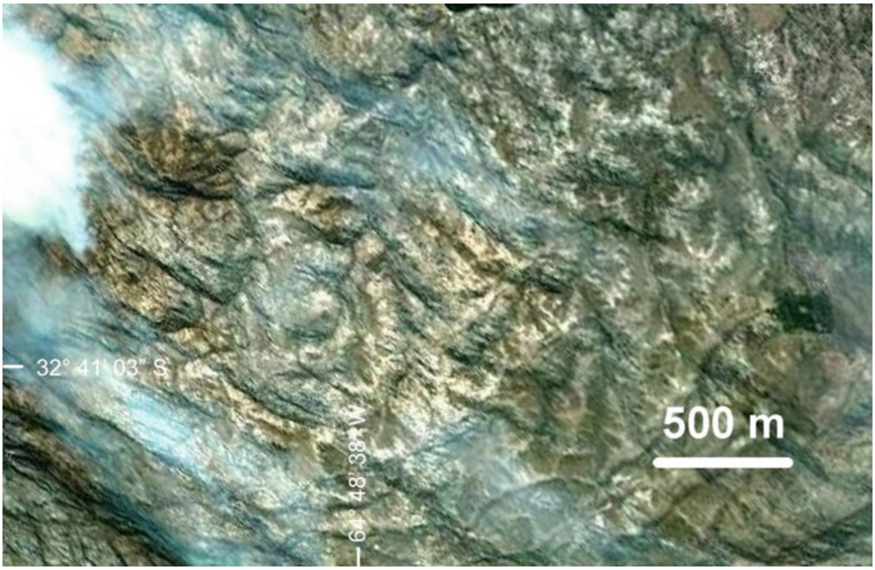

Fig. 2.18 Alpa Corral. *Credit* Image © 2014 DigitalGlobe

2.10.6 Alpa Corral (32° 41′ S, 64° 50′ W)

This oblong depression (Fig. 2.18), 7.7 × 9.4 km across, 250 m depth, is related with the intrusions of the El Talita and, mainly, the Alpa Corral formations, two post-tectonic monzogranites that intruded the Early Paleozoic basement of the Sierras Pampeanas during Late Devonian times (Pinotti et al. 2002).

2.11 South Atlantic Geophysical Anomaly: Islas Malvinas/ Falkland Islands (51° S, 62° W)

Although at a very speculative level, a possible large impact structure has been proposed for the Patagonian continental shelf, near the Malvinas/Falklands Islands, east of Santa Cruz Province. A possible large Carboniferous–Permian impact crater site could be present in the region. A 200 km in diameter, circular Bouguer gravity anomaly has been reported in the South Atlantic Ocean, to the northwest of the Malvinas/Falklands archipelago (Fig. 2.19). It has been interpreted as a large Late Paleozoic impact site (Rampino 1992a, b). A circular structure, of a very large diameter, is located in the ocean floor, a few kilometers offshore to the northwest of the Gran Malvina Island and it is covered by younger sediments. In the gravity field maps there is a central circular area of low negative gravity values surrounded by a

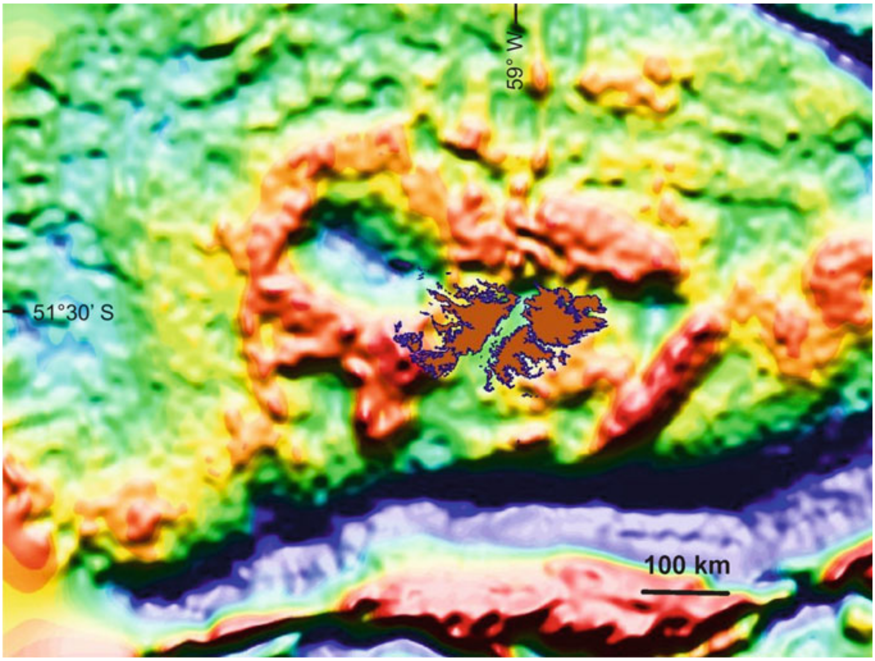

Fig. 2.19 Islas Malvinas/Falkland Islands. *Credit* British Geological Survey

200–250 km circular ring of positive values. The structure could be a complex impact structure of the gigantic central peak ring basin type. Immediately south from the rim of this anomaly, the Paleozoic platform is transected by WNW-ESE-oriented, northward dipping thrust sheets that may have a similar trend as structures observed onshore in the 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 the gravity low is clearly adjusted to the position of the thrusts. Aeromagnetic data also exhibit a relatively low circular anomaly in the same area, which is a gigantic 250 km wide circular magnetic anomaly.

There are also seismic reflection profiles of this structure obtained by the Western Geco Petroleum Company, United Kingdom. These seismic reflection profiles show a basin, probably a sedimentary one, in the area of the circular structure (P. Richards, private communication).

This basin has been interpreted by the geologists of the British Geological Survey as a complex sedimentary basin of Permo–Triassic age and it has recently been re-dated as of Carboniferous–Permian age (D. Aldiss, private communication; P. Richards, private communication). The Permo–Carboniferous age for the NW Malvinas circular basin is in fact just a tentative age dating. During the Permo–Carboniferous times the entire area of Malvinas Islands was covered by a large polar ice cap. Any large impact event during that time should have impacted first on the thick ice polar glaciers.

This site demands more intensive and detailed research to be finally accepted as a new large impact site.

2.12 Problematic Structures Found in the Patagonian Volcanic Landscapes

There are other nonextraterrestrial impact explanations that can interpret these features. Most of them are structures that resemble astroblemes but they are not.

2.12.1 Bajo Hondo (42° 15′ S, 67° 55′ W)

Bajo Hondo is a very interesting site in Patagonia. It is a possible impact crater (Gorelli 1998) but it may be a volcanic feature as well (Fig. 2.20). Its diameter is 4.8 km. This crater is at first glance quite similar to the Barringer crater, USA, but of a much more gigantic size. Bajo Hondo has a 100–150 m raised rim. Bajo Hondo is located in the Somuncurá plateau, 10 km southeast from the Sierra de Talagapa stratovolcano. The Sierra de Talagapa consists of a large 25 × 10 km 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).

Rocca (2003c, 2005) has suggested that Bajo Hondo could be in fact a misinterpreted gigantic simple-type impact crater located on the top of a volcanic plateau.

Fig. 2.20 Bajo Hondo. *Credit* R.D. Acevedo

Likewise, Lonar Lake impact crater in India (a 1.8 km wide simple-type impact crater on basalts) had been misinterpreted as a volcanic caldera for many decades.

However, a recent trip to this locality seems to confirm its volcanic origin. By the available information we can now say that Bajo Hondo is most probably a collapsed basaltic volcanic caldera. It is an interesting example of a volcanic feature that mimics most of the geomorphologic characteristics of a simple impact crater.

2.12.2 Barda Negra (39° 10′ S, 69° 53′ W)

Recent efforts to identify 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 km) in the middle of a large brown basaltic plateau (Fig. 2.21). It has a raised rim. The crater has been mapped as a "salitral" (saline basin), affecting both the Zapala Basalt (top) and the Collón Cura Formation (cineritic tuffs and tuffs) at the bottom. A typical "bajo" (endorheic depression), containing blocks, conglomerates and sands with diatomites (the Tula mine) as a window in the basaltic plateau (this is in no conflict with the hypothesis of an impact crater), has been described. 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 the older lava floods. Then, the age of the Barda Negra's crater is estimated in less than 10 Ma (Ocampo et al. 2005). Recently, 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 (S.P. Wright, private communication). However, it is not certainly conclusive (A. Garrido, private communication). The crater is most probably a volcanic structure, for instance like a maar, but it could still be a new meteorite impact crater.

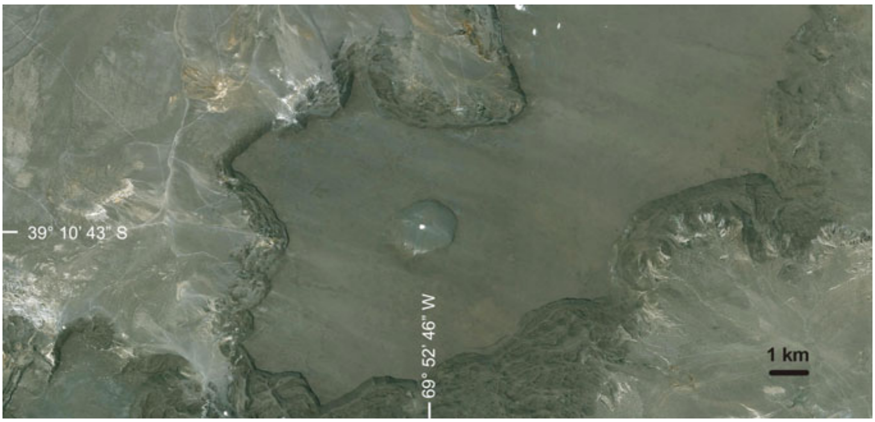

Fig. 2.21 Barda Negra. *Credits* A. Garrido, © 2010 Inav/Geosistemas SRL, © 2010 Cnes/Spot Image, Data SIO, NOAA, U.S. Navy, NGA, GEBCO

2.12.3 Telsen (42° 28′ S, 67° 27′ W)

This depression has the shape of a saucer (Fig. 2.22). It has 850 m in diameter and 42 m in depth. It is located on Cenozoic volcanic rocks and could be a volcanic apparatus.

2.12.4 Llama Niyeo (41° 55′ S, 68° 40′ W)

It is a circular depression on a volcanic plateau (Fig. 2.23), with a diameter of 1.12 km, and a depth of 134 m. Most likely, it is a maar.

2.12.5 Cortaderas (41° 08′ S, 66° 52′ W)

Radial marks that are common characteristics of impacts lead us to think in an extraterrestrial origin for the "bajos" (endorheic depressions) of the basaltic Meseta de Somuncurá, like the Cortaderas structure (Fig. 2.24) and others, but which are in fact maars.

Fig. 2.22 Telsen. *Credit* © 2014 Cnes/Spot Image

Fig. 2.23 Llama Niyeo. *Credit* © 2014 Cnes/Spot Image

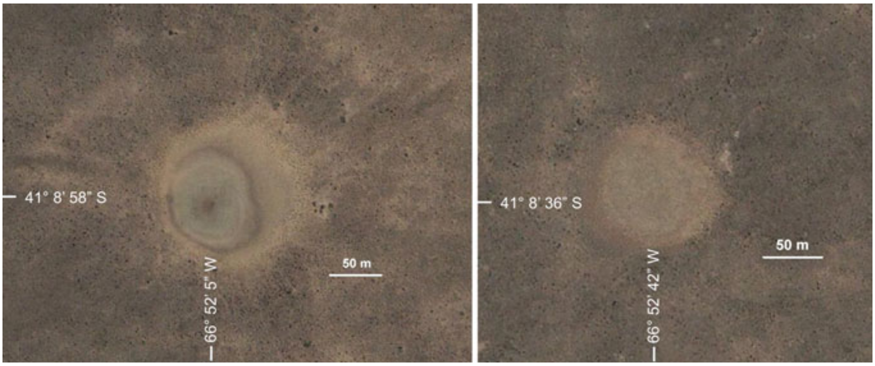

Fig. 2.24 Cortaderas. *Credit* Image © 2014 DigitalGlobe

2.12.6 Pali Aike (52° 04′ S, 69° 29′ W)

This is not a very well-defined circular structure. Its diameter is about 100 m. It is located on the basaltic area of the large Pali Aike volcanic field of Quaternary age. Most likely, it is a maar, but in this case there are many radial fractures that may be characteristic of simple-type impact craters (Fig. 2.25).

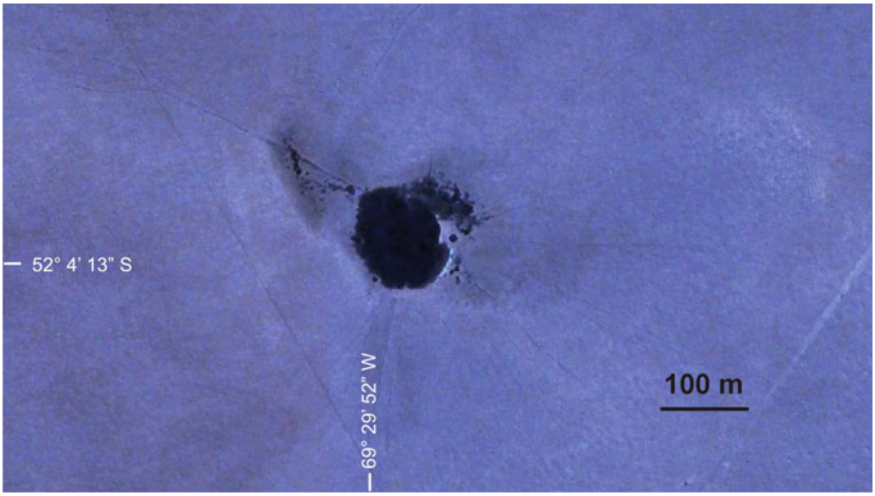

Fig. 2.25 Pali Aike. *Credit* Image © 2014 DigitalGlobe

2.12.7 Laguna Sirven (46° 50′ S, 68° 53′ W)

It is a crater of 2.63 km in diameter and 200 m in depth. The local geology is composed of Miocene basalts and the sedimentary rocks of the Chubut Group (Upper Cretaceous). Its age would be Tertiary. It could correspond to an old volcanic caldera (Fig. 2.26).

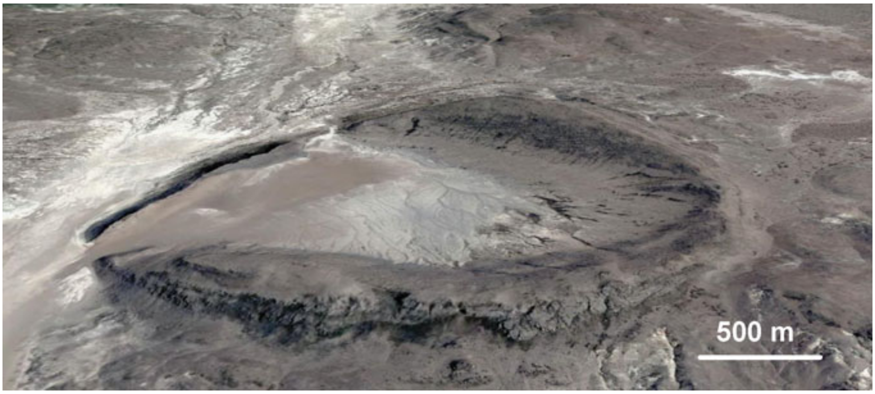

Fig. 2.26 Sirven. *Credit* Image © 2014 DigitalGlobe

2.12.8 Gran Altiplanicie Central (48° 25′ S, 70° 08′ W)

Rocca (2003a) has identified, by means of interpretation of Landsat imagery, a quadrangular structure in the Meseta de la Gran Altiplanicie Central (Fig. 2.27). It is an isolated crater (with a diameter of 700 by 750 m) in the middle of a large dark basaltic plateau. When aerial photographs of the area were obtained, they proved that this structure has a raised rim. The lava in the surrounding plateau was erupted from ground fissures during the Miocene.

2.12.9 Gregores (48° 37′ S, 70° 02′ W)

Another isolated structure (Fig. 2.28), with a diameter of 550 m and a depth of 30 m, over melanocratic lavas beside volcanic cones (c.f. Gran Altiplanicie Central).

2.12.10 Meseta del Canquel (44° 28′ S, 68° 35′ W)

New craters mentioned as possible simple-type impact structures located in a Y-shape configuration on an olivine-basalt plateau were reported from Landsat

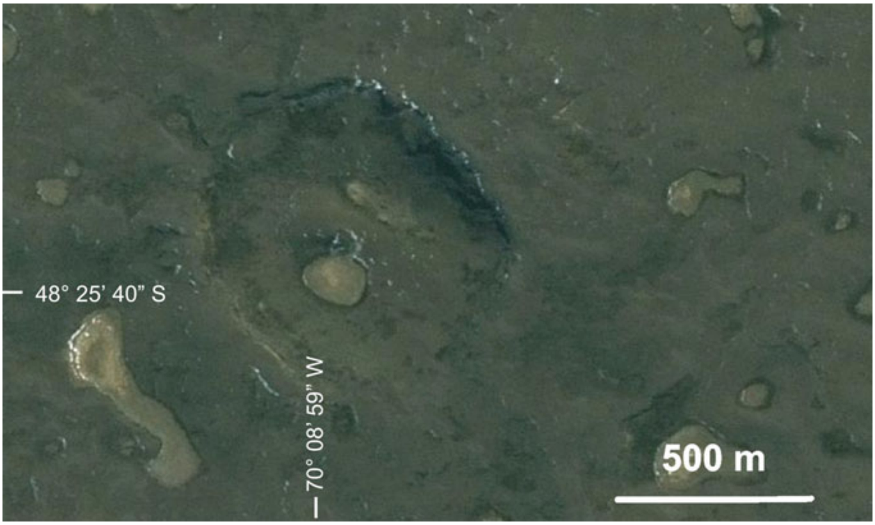

Fig. 2.27 Gran Altiplanicie Central. *Credit* © 2014 Cnes/Spot Image

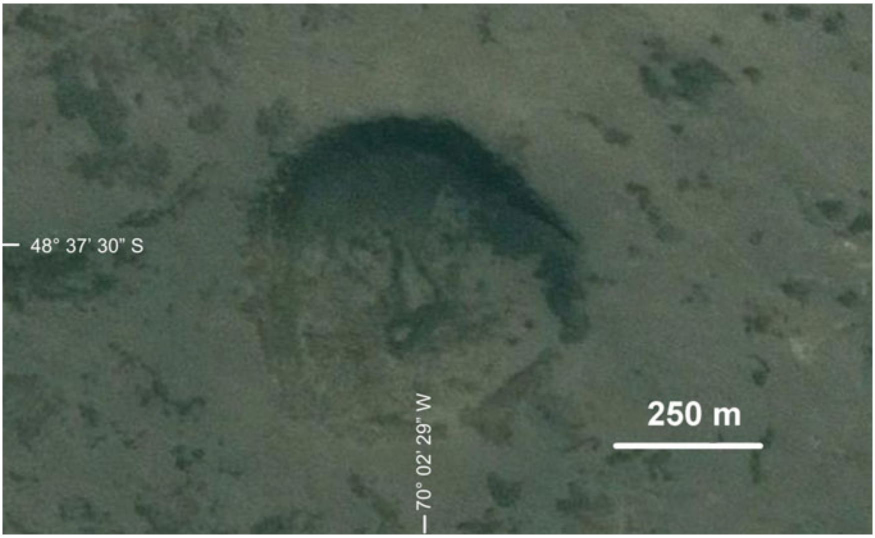

Fig. 2.28 Gregores. *Credit* Image © 2014 DigitalGlobe, © 2014 Cnes/Spot Image

satellite imagery (Fig. 2.29). Craters show raised rims. The diameters are as follows: A: 1.3 km; B: 0.8 km; C: 0.6 km. Their age is estimated in less than 20 Ma (Rocca 2006). These are almost certainly volcanic craters.

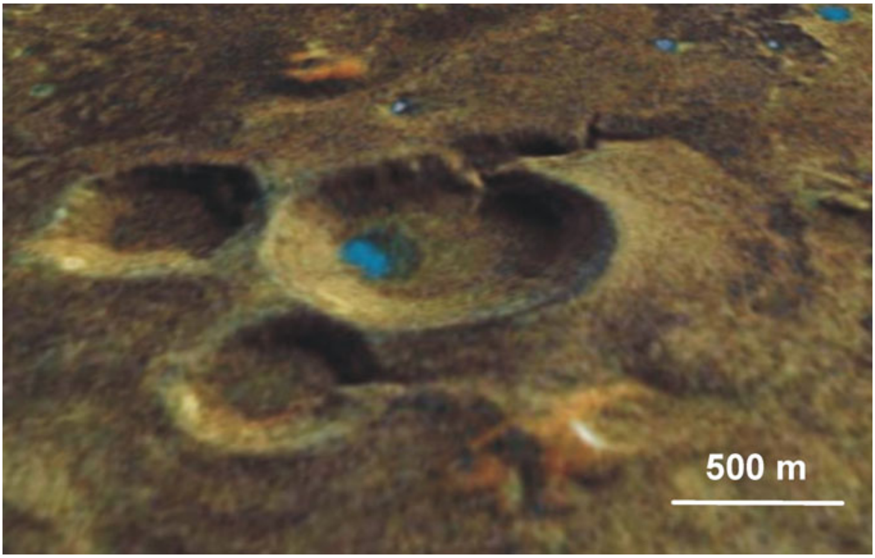

Fig. 2.29 Canquel. *Credit* © 2009 Inav/Geosistemas SRL, Image © 2009 Terra Metrics

2.13 The Impact Ejecta of the Atlantic Coast, Buenos Aires, and La Pampa Provinces: The so-Called *"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 loess-like deposits of Tertiary–Quaternary age exposed in the cliffs along the southeastern portion of the Atlantic Ocean coast of Buenos Aires Province. These impactites are locally known as "*escorias*" (that is, scoriaceous fragments of greenish–brownish glass) and "*tierras cocidas*" (a brick-like, reddish orange rock). They are widespread as defined layers in several sites along the Pampas plains. At present, they have been interpreted by most of the scientists who have studied them as distal asteroid or comet impact ejecta materials. Early in the twentieth century there was a strong discussion about the origin of these materials. On one hand, the Argentine naturalist Florentino Ameghino believed the "*escorias*" and "tierras cocidas" were the product of wild straw fires made by ancient prehistoric men (Ameghino 1908, 1909a, b, c, d, 1910; Romero 1912). Florentino Ameghino was convinced by the examination of the specimens found in his collection that the "*escorias*" and "*tierras cocidas*" were the result of wild straw fires. The wild straw plants, locally known as "*penacho blanco,*" "*paja brava*" or "*cortadera*" (*Gynerium (Cortaderia) argenteum* Nees), was reported by local peasants to produce masses of scoriaceous glass following fires under severe drought conditions (Ameghino 1909a, b, c, d). Thus, Ameghino's idea was that wild straws burnt by prehistoric men were responsible for the production of the clusters and strata of "*escorias*" and "*tierras cocidas,*" as they occur enclosed within the Late Tertiary–Quaternary loess and loess-like sediments of the Pampas plains. No recent tests of this hypothesis have been performed. On the other hand, there were other scientists who believed these materials were of volcanic origin (Outes et al. 1908; 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). More recently, some other hypothesis about the origin of the "*escorias*" and "tierras cocidas" were proposed (Cortelezzi 1971) and some spread vitreous material like "*escorias,*" interpreted as possible fulgurites, have been shown in the area as well (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 the existence of diaplectic glasses of quartz and feldspar are also very good and quite conclusive evidence of a giant meteorite impact origin which would be related to the "*escorias.*" Although the "*escorias*" could be classified as impact melt breccias, their unique characteristics may warrant a new term, herin proposed: "pampasitas," thus 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 loess-like deposits would have been rapidly destroyed by erosion processes. According to published information (Schultz et al. 1998; 2004a, b; Zárate and Schultz 2002; Zárate et al. 2004) several impact event layers are well identified in the area. Radiometric ages were obtained by high-resolution $^{40}Ar/^{39}Ar$ dating. Recently, preserved fossil plant remains have been reported to be found enclosed inside the glass of the "escorias." They are interpreted as remains of ancient plants which became enclosed in the impact glass melt breccia during the impact event (Schultz et al. 2014).

The potential impact sites in the zone are:

I. Centinela del Mar (38° 26′ S, 58° 14′ W, City of Necochea area): Layer A: 0.23 Ma. Layer B: 0.44 Ma.
II. Chapadmalal (30° 11′ S, 57° 38′ W, City of Mar del Plata area): 3.30 Ma.
III. Pehuén Có (38° 35′ S, 62° 13′ W, City of Bahía Blanca area): 5.33 Ma.
IV. Laguna Chasicó (38° 50′ S, 63° 7.3′ W) glass layers yielded an age of 9.24 Ma.

Reported Impact craters/structures in the area.

2.13.1 *La Dulce (38° 14′ S, 59° 12′ W)*

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 (Fig. 2.30). The structure has 2.8 km in diameter and it could be classified as a simple-type impact

Fig. 2.30 La Dulce. *Credit* © 2013 Inav/Geosistemas SRL, Image © 2014 DigitalGlobe

crater. A steep cliff-lined rim bounds the La Dulce crater on its eastern and southern sides. There the rim rises from 25 to more than 40 m above the interior floor and 10–20 m above the exterior plain. Radar data show that the northern rim is a much subdued, but nonetheless complete, accurate structure. This structure has been modified by the nearby Río Quequén. 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. This should be conclusive evidence of the impact origin of the structure (Harris et al. 2007). Age for this crater has been estimated in 0.445 Ma; in this case, this crater could be associated to one of the impact layers of the Centinela del Mar area.

2.13.2 General San Martín (38° 00′ S, 63° 18′ W)

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 (Fig. 2.31). It has 10.0–12.0 km in diameter. Although unimpressive in satellite images, the General San Martín circular structure is unambiguous when observed 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

Fig. 2.31 San Martín. *Credit* © 2013 Inav/Geosistemas SRL, Image © 2014 DigitalGlobe, © 2014 Cnes/Spot Image

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 still 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" or "tierras cocidas"* layer have been yet associated to this possible impact structure.

2.13.3 D'Orbigny (37° 38′ S, 61° 43′ W)

An embankment next to the fall of the rare D'Orbigny angrite (Acevedo et al. 2014c) forms an arc of circumference with a radius of 275 m (Fig. 2.32).

2.13.4 Bajo del Gualicho (40° 22′ S, 65° 15′ W)

This is a huge oblong W–E depression of 70 × 40 km and 240 m depth (−73 below sea level) northeast of the Macizo Norpatagónico (Fig. 2.33), a massif composed of Proterozoic and Eo-Palaeozoic metamorphic rocks. A circular gravimetric Bouguer

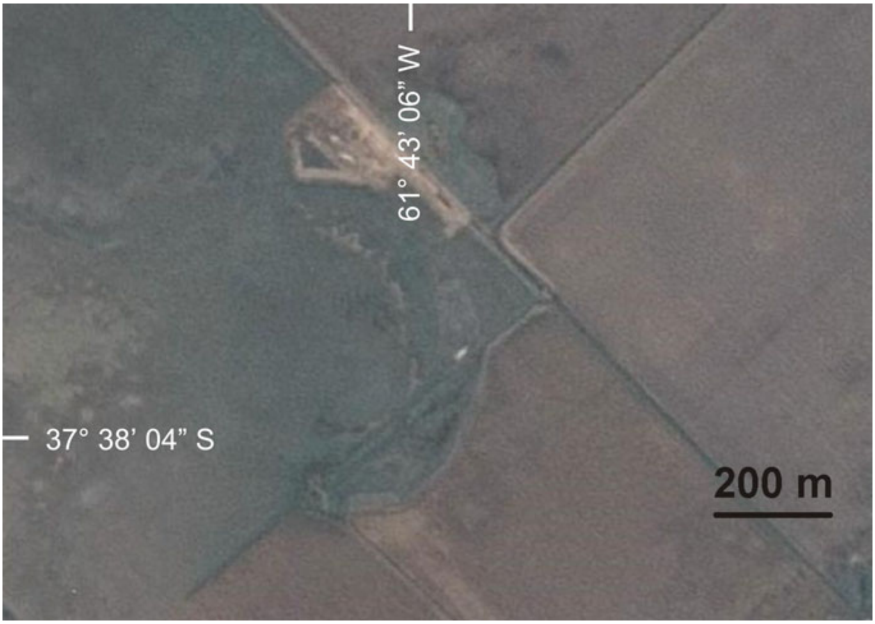

Fig. 2.32 D'Orbigny. *Credit* © 2009 Inav/Geosistemas SRL, © 2009 LeadDog Consulting, © 2009 Cnes/Spot Image

Fig. 2.33 Bajo del Gualicho. *Credit* Data SIO NOAA, U.S. Navy, NGA, GEBCO, Image Landsat

anomaly of clear negative values located in the area could be a covered complex impact structure. The diameter of the gravity anomaly is of 60 km. If the anomaly is in fact an impact structure, then it would be one completely covered and with probably an age older than several million years.

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