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A POSSIBLE NEW VERY LARGE IMPACT STRUCTURE IN MALVINAS ISLANDS

Una nueva posible estructura de impacto de gran tamaño en las Islas Malvinas

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Resumen. Una enorme posible estructura de impacto de gran tamaño está presente en la región de las Islas Malvinas. La estructura tiene 250 a 300 kilómetros de diámetro y su edad sería de al menos 300 millones de años. Está localizada al NW de la Isla Gran Malvina, localizada bajo el agua y completamente tapada por sedimentos más jóvenes. Se da la información detallada geofísica y geológica del área que apoya fuertemente la existencia de una gran estructura de impacto en dicho lugar.

Palabras clave. Estructuras de impacto, Islas Malvinas.

Abstract. A very large possible new impact structure is present in the Malvinas/Falkland Islands area. The structure has 250-300 kilometers in diameter and is at least 300 million years old. It is located underwater to the NW of Gran Malvina Island (=West Falkland island) and completely covered by younger sediments. Geophysical and geological information of the area is given and it strongly supports the existence of a new large impact structure at the site.

Key words. Impact structures, Malvinas/Falkland Islands.

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.

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 giant meteorite impact sites is the following:

Simple crater. it is the smallest 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 around 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 around 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 approximately 1.0 kilometer in diameter, the shock pressures and temperatures produced upon impact are sufficient to completely melt and even vaporize the impacting body and some of the target rocks. So no meteorite specimens 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 high-pressure polymorphs variations of minerals (high pressure forms of quartz: coesite, stishovite), and rocks melted by the intense heat of the impact (French, 1998).

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 are 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 (French, 1998).

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 asteroid/comet impacts. They are not found in volcanic environments. Their presence therefore is a primary criterion for recognizing that an impact event has occurred (French, 1998).

Some terrestrial structures have morphological characteristics consistent with both a simple-type craters or complex impact structures, but lack either pieces of the impacting body (meteorites) or definitive signs of shock metamorphism. This may be because suitable samples cannot be recovered as they are submerged beneath a deep circular lake, buried under post-impact sedimentary rocks, or almost completely eroded. Continued investigation may yet produce evidence of shock metamorphism at some of these possible impact craters or structures (French, 1998; Grieve, 1990, 2001; Melosh, 1989; Osinski and Pierazzo, 2012).

RESULTS

The giant circular geophysical structure at Malvinas (S 51° 00′, W 62°00′)

A possible very large Paleozoic impact site could be present in the Malvinas/Falkland Islands. A 250-300 kilometers wide circular Bouguer gravity anomaly has been reported in the area and it has been interpreted as a new possible large late Paleozoic impact structure (Rampino, 1992 a, b; Figure 1).

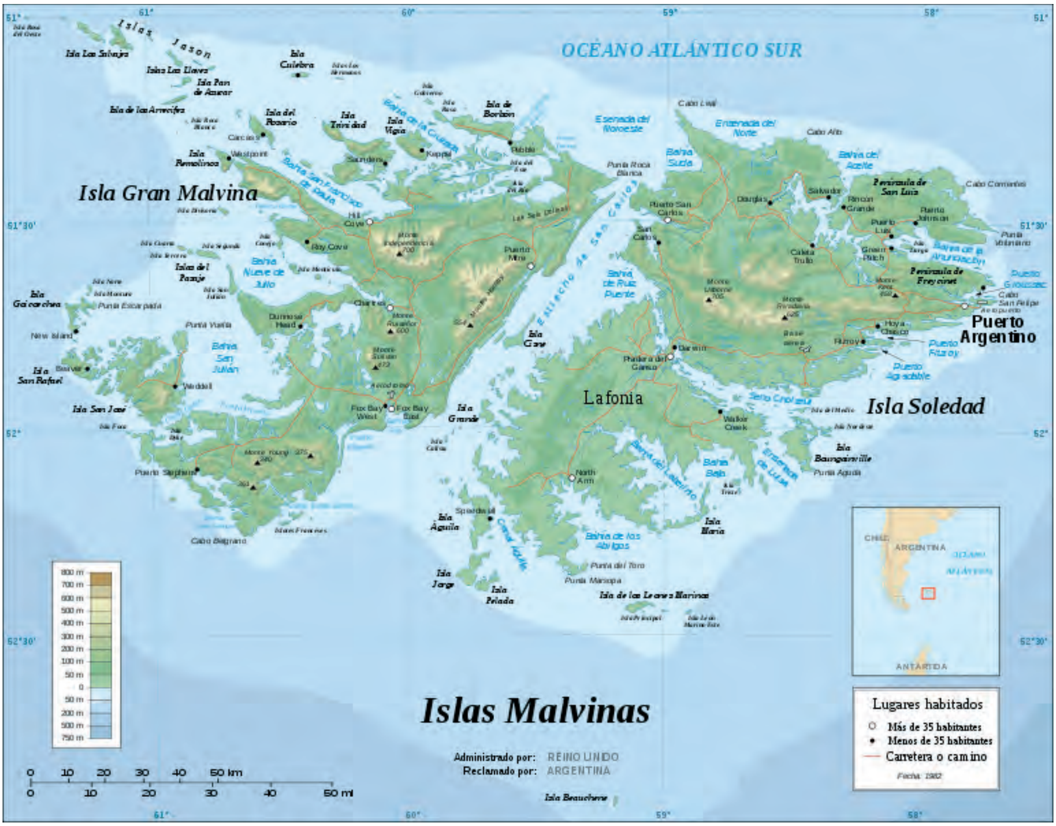

Figure 1 - Map of the Malvinas Islands.

Since the very brief report by Rampino in 1992, nobody has made detailed research of this site. So, we have performed an exhaustive search for additional new geophysical information on the subject and made a detailed analysis of the case.

Detailed geophysical maps of free air and Bouguer regional gravity anomalies were consulted at Servicio Geológico y Minero de la Argentina (SEGEMAR); that is the Geological Survey of Argentina, (SEGEMAR, 1997) in Buenos Aires; at the British Geological Survey in the United Kingdom (BGS, 1998) and at internet geophysical databases (e.g., World Gravity Map -WGM2012 model, Topex).

A circular structure of 250-300 kilometers in diameter was confirmed in the Malvinas/ Falkland Islands area. It is located underwater a few kilometers offshore to the NW of the Gran Malvina Island (= West Falkland; S 51º 00', W 62º 00').

In the offshore regional free air residual gravity maps there is a central circular area of low gravity values with a minimum value of -30.6 milligals (mGal) surrounded by at least one 250-300 kilometers wide circular ring of positive values (maximum +47.6 mGal) both in clear contrast with the local average values of the zone (+2.5 to -2.5 mGal). This is typical of large impact structures (French, 1998; Osinski and Pierazzo, 2012).

The situation of the Malvinas anomaly is very similar to the case of the Chicxulub multi ring impact structure (170 kilometers in diameter) in Yucatan, Mexico which was also discovered from the associated negative gravity anomaly in PEMEX free air gravity maps. In the case of Chicxulub, the negative anomaly has minimum values of -20 mGal to -30 mGal, very similar to the numbers of the Malvinas structure, (Hildebrand *et al.*, 1991; Figures 2,3),
The structure has no expression in the topographical submarine maps of the area. No submarine depression is visible (Figure 4).

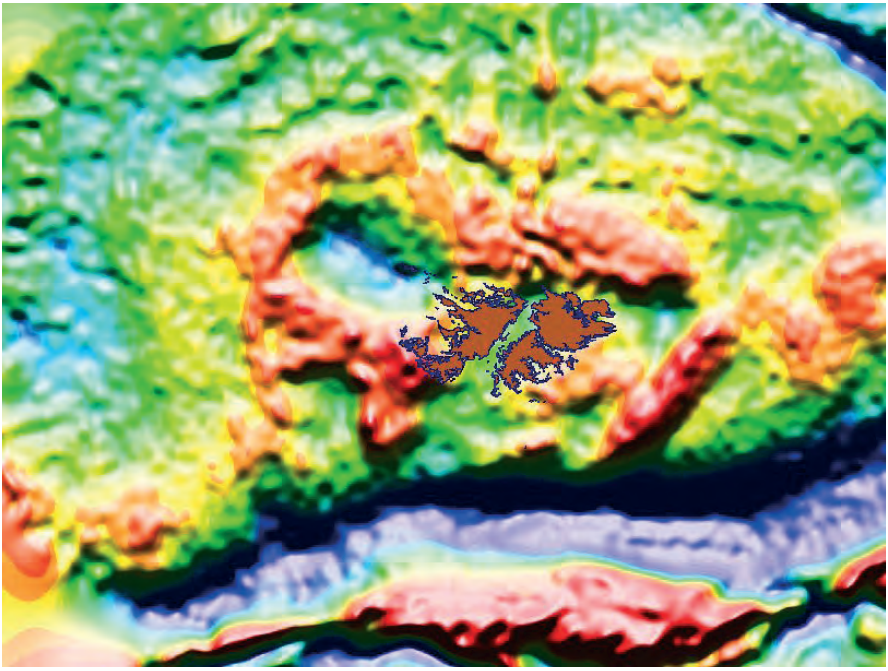

Figure 2 - Offshore regional residual gravity anomalies of the Malvinas area. The giant 250-300 circular anomaly is clearly visible to the NW of Gran Malvina Island. Source of the image: British Geological Survey, UK.

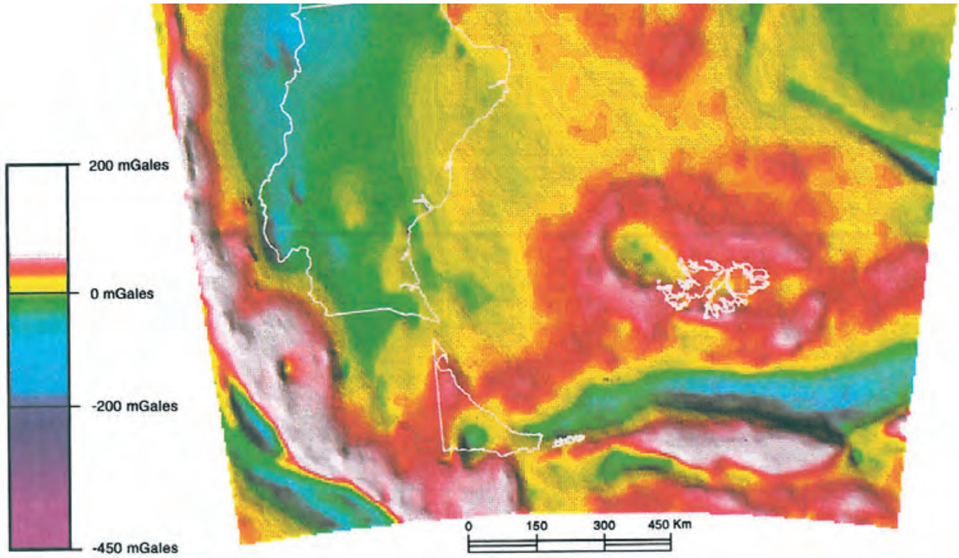

Figure 3 - Another image of the offshore regional gravity Bouguer anomalies of the Malvinas area. Source: SEGEMAR.

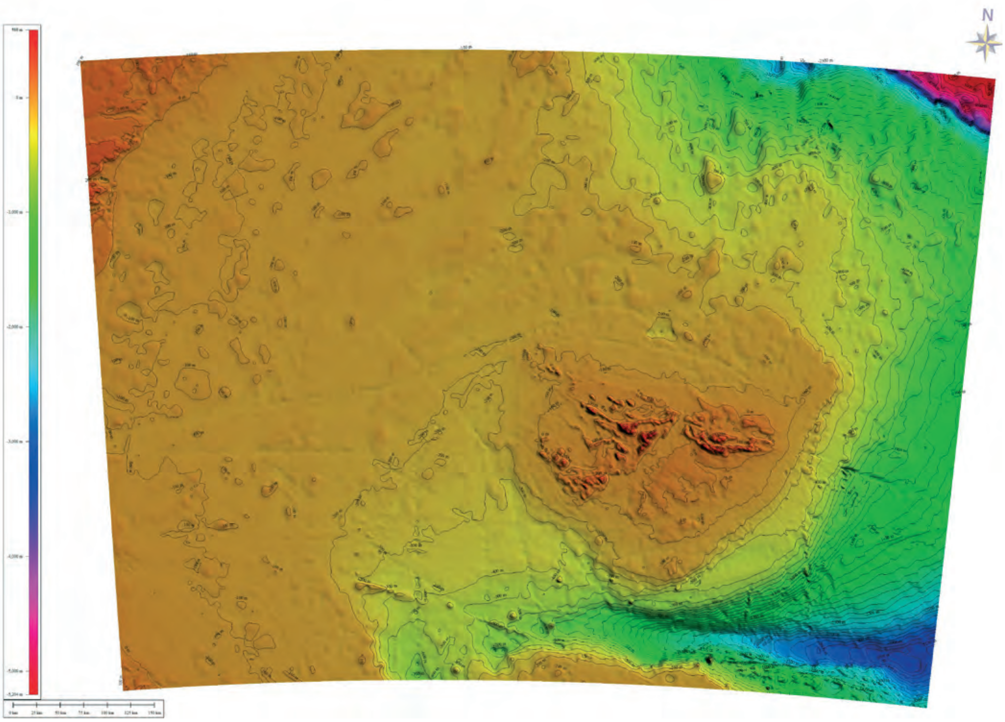

Figure 4 - Submarine topographic map of the Malvinas area. No expression of the structure is visible in the ocean's floor. The structure is completely covered by younger sediments. Source: Topex.

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 West Falkland. Both satellite and marine gravity data exhibit relatively low anomalies just to the north of these thrusts (Richards *et al.*, 1996).

Seismic Tomography images (http://ds.iris.edu), Gravity profiles and crustal-T maps show inhomogeneity in the crust-mantle limit and also clear mantle plug of a central uplift in the central part of this

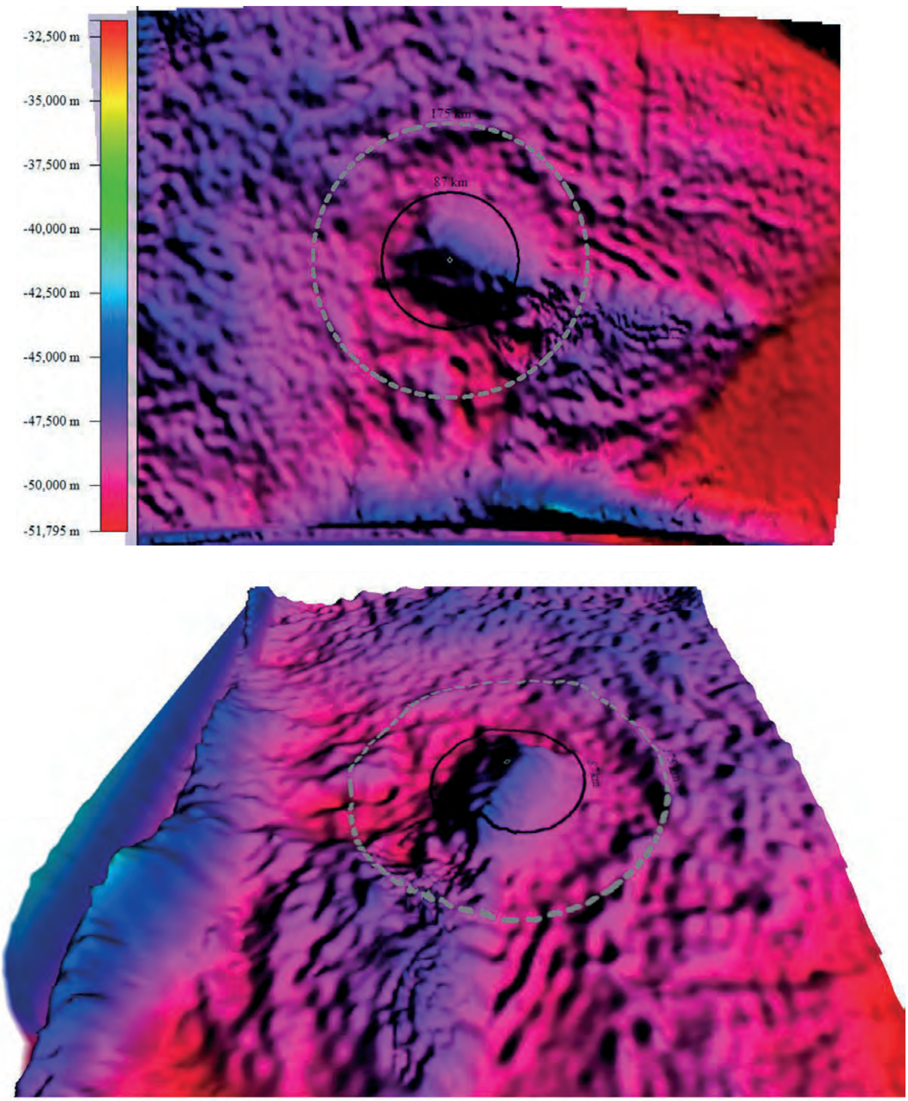

Figure 5 - Two gravity crustal-T maps of the Malvinas area. Note the central mantle plug uplift at the center of the circular structure. Source: World Gravity Map

structure. This is consistent with the existence of the large central uplift of a giant peak ring or multi ring impact structure. It seems that the impact shock waves have thinned and disrupted the Precambrian crust of the area. That is again consistent with a large impact event and a subsequent mantle-crustal rebound (Figure 5).

The low gravity anomaly possibly indicates the presence of a basin. This basin has been interpreted by the British geologists as a complex sedimentary basin of Permo-Triassic age (Richards *et al.*, 1996) and re-dated in 1998 as Carboniferous-Permian (Aldiss and Edwards, 1998, 1999). Detailed marine seismic reflection profiles of this area are in possession of Western Geco Geophysics Company, London, UK. We had no chance to consult them. However, from references of British colleagues we know that they also show a clear circular "sag basin" in the area of the gigantic circular Bouguer anomaly (Richards, 2003, personal communication).

Aeromagnetic offshore regional maps also exhibit an impressive circular anomaly of about 250 kilometers in diameter in the same area. A central anomaly of high magnetic values is surrounded by the local normal low values. The circular magnetic anomaly reaches to a maximum value of 214 nanotes-las (nT) in clear contrast to the local average values of the zone of only zero nT to 40 nT. (See EMag for Google, and NGDC-720 lithospheric magnetic model, http://geomag.org/models/).

The positive high magnetic anomaly has 250 x 220 kilometers. Again, this is a characteristic of large impact structures (Melosh, 1989; Osinski and Pierazzo, 2012). In fact the Malvinas structure's positive magnetic anomaly is again very similar in its characteristics to the one associated to the Chicxulub multi ring impact structure (170 kilometers in diameter) in Yucatan, Mexico, (Rebolledo-Vieyra *et al.*, 2010; Figures 6 and 7).

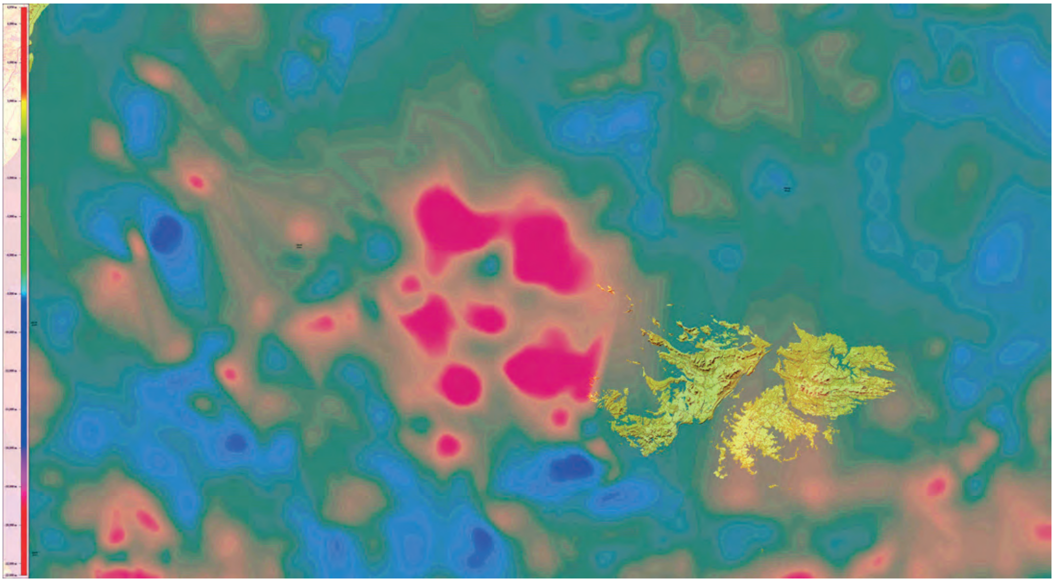

Figure 6 - Offshore map of the residual magnetic anomalies of the Malvinas area. An evident 250 kilometers wide circular positive anomaly is present in the area of the structure. Source: EMag for Google.

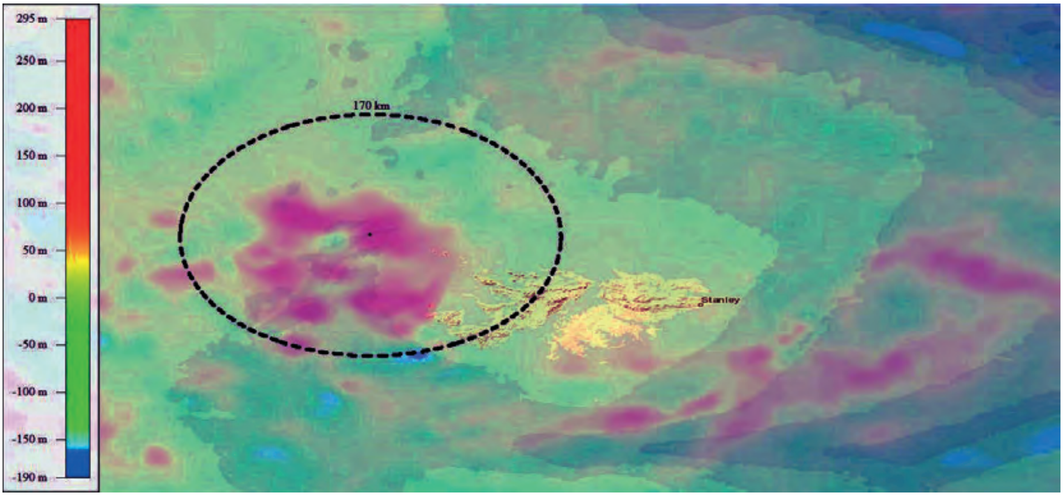

Figure 7 - Offshore regional map of magnetic anomalies of the Malvinas area. The circle around the structure has 170 kilometers in radius. Source: EMag for Google.

The available geophysical information strongly supports the idea that the structure could be in fact an old and covered gigantic central peak ring basin or even a multi ring impact basin. One completely covered by younger deposits.

This area was covered by sub polar glaciers and the polar ice cap during the Carboniferous times (Bellosi and Jalfin, 1984, 1987; Ramos, 1996; Aldiss and Edwards, 1999).

The carboniferous lafonia diamictites/ fitzroy tillite deposits in the Malvinas Islands: are they impact ejecta?

Thick diamictite/tillite deposits are present in both Islands. They are locally known as the Lafonia diamictite or the Fitzroy tillite and are dated as Carboniferous (Bellosi and Jalfin, 1984, 1987; Aldiss and Edwards, 1999). So they are of the same age that the above mentioned circular gigantic geophysical anomaly.

The unit is composed of massive to very weakly thick-bedded sandy diamictite. When fresh it is dark bluish or greenish grey in color.

Rock fragments up to boulder size occur scattered through the dark color sandy matrix of the diamictites/tillites. Some clasts are well-rounded and sub spherical but most are sub angular with a wide range of sphericity. They made up from a few percent to at least 50% of the rock. The maximum clast size and the average clast size both increase overall from East to West. Maximum clast size increases toward the West and the largest clast size reported so far is for granite angular blocks up to 10 to 7 meters wide (Aldiss and Edwards, 1999).

Diamictite/tillite deposits thickness varies from about 900 meters at Hill Cove, Gran Malvina Island (= West Falkland) to 350 meters at Port Fitzroy , Soledad Island (= East Falkland), (Frakes and Crowell, 1967). Again it apparently increases toward the Northwestern direction, that is in the direction were the circular gigantic geophysical anomaly is located. The tillite at Hill Cove area (the most northwestern outcrop site at Gran Malvina) is notable for large numbers of big "erratic" granitic cobble - boulders up to 7 meters in diameter. Could those blocks be related to the so close circular geophysical structure?

Some local quartzite clast type carry "glaciar" striae but they are rare (Halle, 1912). There are also iceberg "dropstones" that are mostly less than 5 centimeters in diameter but may include sub angular granitic gneiss blocks up to 1 meter across (Frakes and Crowell, 1967; Aldiss and Edwards, 1999).

There are also reports of intrusive "diamictite" dykes (Hyam *et al.*, 1997).

Most of the clasts enclosed in the diamictites come from the local Devonian sedimentary sequence directly underlying the diamictite/tillite. Acid igneous Granitic clast are also present and are identical to the granite rocks at Cape Meredith, at the Southern point of Gran Malvina Island (=West Falkland).

Many "erratic" or "exotic" clasts composed of volcanic, carbonates, gneisses and mafic igneous rocks are also present and are not presently known to crop out in the Falkland Islands (Frakes and Crowell, 1967; Aldiss and Edwards, 1999). Those "exotic" rock clasts like e.g., garnet gneiss may come from sites today located underwater and /or excavated from the depth.

DISCUSSION

In some cases impact crater fragmental breccias were misinterpreted and classified as glacial "diamictite/tillite" deposits by the geologists in the past. This was the case of some sites with thick clastic "diamictite" breccia deposits located in Belize and western Cuba, and at present positively associated to the Chicxulub impact crater event proximal ejecta blanket (Oberbeck *et al.*, 1993; Rampino, 1994; Pope *et al.*, 1999). They were in fact giant meteorite impact proximal ejecta and not clastic "glaciar diamictite" deposits.

Cacarajicara Formation of western Cuba is one of the thickest Chicxulub's ejecta deposits in the World. It is a clastic "diamictite" breccia sequence at least 500 meters in thickness. In addition, the case of the clastic "diamictite" breccia from Albion Formation, Albion Island in Belize, is very interesting to compare with the case of the clastic "diamictites" from Malvinas. Like in the case of the Malvina's diamictites, fragmental breccias from Albion Island also show clasts with striae and "erratic" boulders, (Pope *et al.*, 1999).

Although speculative, we suggest here that the diamictite/tillite deposits in the Malvinas /Falkland Islands could be related with the gigantic geophysical circular structure located underwater to the NW of Gran Malvina Island and they may be misinterpreted giant meteorite impact proximal ejecta.

The "erratic" granitic blocks reported in the diamictite deposits could have been excavated from the depth during an impact event at the site of the geophysical anomaly and then launched as fragmental proximal ejecta.

So far nobody has performed a detailed and exhaustive microscope search for shock metamorphic effects in minerals from samples of the Lafonia diamictite/ Fitzroy tillite deposits of the Falkland Islands. We suggest concentrating that study on the enclosed "erratic" clasts and the cobble-boulders, specially the granitic ones.

CONCLUSIONS

A very large 250 to 300 kilometers wide circular geophysical anomaly (visible both in gravity and magnetic maps) is present offshore to the Northwest of Gran Malvina Island (=West Falkland). The analysis of the available geophysical information of this site strongly supports the interpretation that the anomaly is the local expression of a new very large impact structure.

Its age could be tentatively estimated as Carboniferous or perhaps older.

Thick local diamictite/tillite deposits could be related to the geophysical structure and could be impact proximal ejecta. We suggest making a future search for shock metamorphic effects in minerals of the enclosed "erratic" clasts and the cobble-boulders at Hill Cove area, Gran Malvina Island. Special attention should be pay on the granitic ones.

If confirmed as a real site of impact then this structure will be one of the 4 largest impact structures on Earth.

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