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NEW DATA CONCERNING A POSSIBLE VERY LARGE LATE PALEOZOIC IMPACT STRUCTURE IN MALVINAS/FALKLAND ISLANDS

Nuevos datos sobre una posible gran estructura de impacto del Paleozoico tardío en las Islas Malvinas/Falkland

Maximiliano C. L. Rocca

The Planetary Society, Mendoza 2779-16A, Ciudad de Buenos Aires, Argentina. maxrocca2010@gmail.com

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Abstract. A large possible Late Permian (?) new impact structure is present in the Malvinas/Falkland Islands area. The structure has 250 kilometers in diameter. It is located underwater to the NW of Gran Malvina Island (=West Falkland island) and completely covered by younger sediments. New Geophysical information (Marine seismic reflection lines data, gravity, and magnetic maps) of the area is given and it again supports the existence of a new large impact structure at that site. We make comparisons with the Chicxulub impact structure in Yucatan, Mexico.

Key words. Large Impact structures, Late Paleozoic mass extinction, Malvinas /Falkland Islands.

Resumen. Una enorme posible estructura de impacto del Pérmico final se registra para la región de las Islas Malvinas. La estructura tiene 250 kilómetros de diámetro. Está localizada al NW de la Isla Gran Malvina, localizada bajo el agua y completamente tapada por sedimentos más jóvenes. Se da aquí nueva información detallada geofísica (perfiles marinos de reflexión sísmica, y mapas de anomalías gravimétricas y magnéticas) del área que apoya la existencia de una gran estructura de impacto. Se hacen aquí comparaciones con la estructura de impacto de Chicxulub en Yucatán, México.

Palabras clave. Estructuras gigantes de impacto, extinción en masa del Pérmico final, Islas Malvinas.

INTRODUCTION

Today, impact cratering is recognized as the dominant surface-modifying process in the Solar planetary system. During the last forty years, planetary scientists have demonstrated that our Moon, Mercury, Venus and Mars are all covered with asteroids/comets impact craters and structures. However, only recently it has been accepted the fact that impact cratering is an important geologic process working on the Earth's surface too. It is the new geology of the XXI Century (Rampino, 2017).

In this essay, new geophysical information (marine seismic reflection lines, gravity and magnetic anomalies maps) for the possible Malvinas / Falklands structure is presented for the first time.

MATERIALS AND METHODS

The general geomorphological classification of giant meteorite impact sites is the following:

Simple crater: it is the smallest impact structure, a bowl-shape like 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) (French, 1998).

Complex structures: They are large impact structures (from 4.0 km up to more than 300 kilometers in diameter) characterized by an almost perfect "bull's eye" circular shape configuration, a central uplifted region, a generally flat floor, and extensive inward collapse around the rim (deep normal faults), (French, 1998; Osinski and Pierazzo, 2012).

Complex impact structures are classified by its shape and size in:

1) Central peak impact structures of 4 to 25 kilometers in diameter.
2) Peak ring impact structures of 25 to 150 kilometers in diameter
3) Multi ring impact basin structures of more than 150 kilometers in diameter.

There are several proxies that are employed with the aim to recognize the presence and classification of impact craters:

1- The use of satellite imagery and remote sensors geophysical data (gravity and magnetic) has been always key to identify new impact craters and structures especially when they are buried and/ or eroded (Osinski and Pierazzo, 2012; Rampino, 2017).
2- The identification of the so-called "shock metamorphic effects" in the minerals and rocks inside and around the possible new impact crater or structure are key to a formal confirmation of its asteroid/comet giant meteorite impact origin.

They are the consequence of the pass of the very high-pressure shock wave during the first seconds of the "contact and compression" stage of the impact event itself. The powerful shock wave passage transforms the internal atomic structure of the crystals in the minerals of the impacted area and can creates new unique High-Pressure Polymorphs of those minerals like, e.g. Coesite and Stishovite which are High Pressure Polymorphs of Quartz.

The identification of those unique High-Pressure Polymorphs of Quartz (Coesite and Stishovite), the microscopic identification of the so called Planar Deformation Features (PDFs) in mineral crystals, especially in Quartz, diaplectic glasses, and the "in situ" surface visual identification of the so called "shatter cones" are fundamental for impact structures confirmation. Due to space limitations, we are not going to review here the basic characteristics and properties of each one of those "shock metamorphic effects" features (see details in French, 1998; Melosh, 1989; Osinski and Pierazzo, 2012).

Largest impact structures are sometimes evident in geophysical data as large circular gravimetric and magnetic anomalies (Pilkington and Grieve, 1992).

RESULTS

The Chicxulub Impact Structure in Yucatan, Mexico

The prototype of a very large impact structure identified by the use of geophysical data is the 66 Ma old Late Cretaceous Chicxulub Impact Structure, in Yucatan, Mexico.

The Chicxulub impact structure is estimated to be about 180 to 200 kilometers in diameter and 20 kilometers in depth, well into the continental crust depth. (Hildebrand *et al.*, 1991; Gulick *et al*., 2013). It possesses a peak ring, a central basin filled with an impact melt sheet and a surrounding annular trough limited by deep normal faults (Gulick *et al.*, 2013). It is the third largest confirmed impact structure on Earth.

The Chicxulub structure currently underlies the Northern coastline of the Yucatán Peninsula, as can be seen in gravity maps of the area as a large circular negative anomaly. At the time of impact, the Gulf of Mexico covered the northern part of the peninsula, so the impact occurred into a shallow sea. Sedimentation on the floor of the gulf filled in the crater and eventually buried it beneath 1 kilometer of sediment. (Gulick *at al.*, 2013)

The Chicxulub impact basin structure has the typical geomorphological "bull's eye" concentric multi ring basin configuration of large lunar, martian, venusian and mercurian impact basin structures. The subsurface geomorphological multi ring basin shape configuration of the Chicxulub structure can be easily seen in gravity maps of the Northwestern margin of the Yucatán Peninsula as a large roughly 180 to 200 kilometers wide negative anomaly (Hildebrand *et al*., 1991 and 1995; Gulick *at al.*, 2013).

Both the Free Air and the Bouguer gravity anomalies maps of the Yucatan area show its circular multi ring basin configuration (Hildebrand *et al*., 1991 and 1995; Gulick *et al.*, 2013).

A large 100 kilometers wide positive magnetic rose-like shaped anomaly showing a circular configuration is also associated to the Chicxulub structure (Pilkington and Hildebrand, 2000; Rebolledo-Vieyra *et al.*, 2010)

The Late Paleozoic geophysical structure at Malvinas (S 51º 00', W 62º 00')

A possible very large Late Paleozoic (Late Permian?) impact structure could be present in the Malvinas/Falkland Islands. It was discovered and first reported by Rampino, 1992.

In our previous publications, we have already described the most basic characteristics of a possible giant 250 km wide impact structure in the area (Rocca and Baez Presser, 2015; Rocca, 2016; Rampino *et al.*, 2017; Rocca *et al.*, 2017; Baez Presser *et al.*, 2019).

A 250 kilometers wide circular Bouguer and Free Air gravity anomaly has been reported in the area and it has been interpreted as a new possible large Late Paleozoic impact structure. Available maps are present and published by the SEGEMAR, 1997, the British Geological Survey's (Aldiss and Edwards, 1998's map) and at internet geophysical databases (e.g., World Gravity Map -WGM2012 model after Sandwell *et al.*, 2014; NASA TOPEX, etc.).

A roughly circular structure of 250 kilometers in diameter is clearly visible in the Malvinas/Falkland Islands area. It is located underwater offshore a few kilometers to the

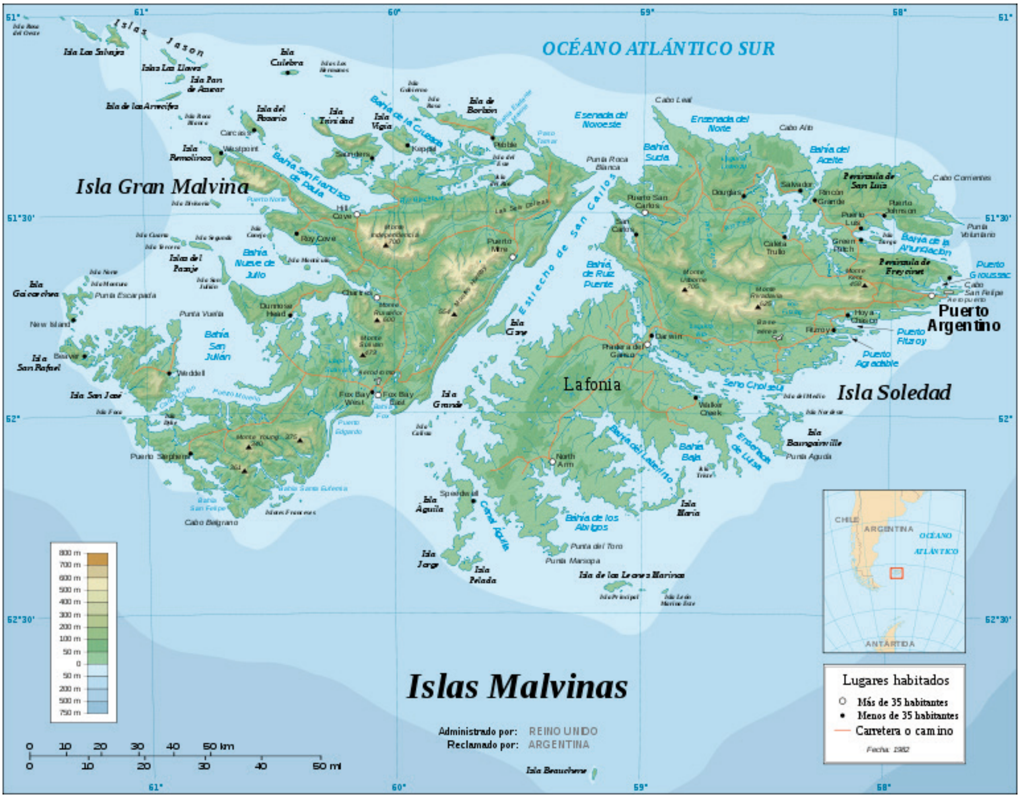

Figure 1 - Map of the Malvinas= Falklands Islands.

NW of the Gran Malvina Island=West Falkland island (S 51º 00′, W 62º 00′). It shows a minimum value of -30.6 milliGals (mGal) surrounded by at least one 200 kilometers wide roughly circular ring of positive values (maximum +47.6 mGal), (Rocca *et al.*, 2017). This is typical of large impact structures (French, 1998; Osinski and Pierazzo, 2012) and very similar to the values of the gravity anomalies associated to the Mesozoic 200 kilometers wide Chicxulub impact structure in Yucatan, Mexico (*cf.* Hildebrand *et al.*, 1991 and 1995; Grieve *et al.*, 2008; Gulick *et al.*, 2013).

The Malvinas=Falklands structure has no expression in the topographical submarine maps of the area. No submarine depression is visible. Seabed is almost flat. (NASA, TOPEX satellite database).

This negative gravity anomaly indicates the presence of a large buried basin. This basin has been interpreted by the British Geological Survey's petroleum experts geologists as a "Permian-Triassic complex sedimentary basin controlled by thrusts" (Richards *et al.*, 1996) and re-dated in 1998 as Carboniferous-Permian (Aldiss and Edwards, 1998) by onshore sedimentary strata correlations and guesses.

We believe that the earlier Late Permian (?) age for this "basin" is the correct one. Since there are no Late Permian strata exposed onshore in the Islands, the British geologists guessed that no Late Permian strata could be present offshore too. This is only a stratigraphic guess and since there are no wells data (no drill core samples) taken from the exact site of the "basin" no absolute stratigraphic nor radiometric dating of the Gran

Malvina=West Falkland's offshore "basin" can be made.

Satellite magnetic offshore regional maps exhibit an impressive rose-like circular anomaly of about 250 kilometers in diameter in the same area. That anomaly is what I have named *THE ROSE OF THE MALVINAS=FALKLANDS* (Rocca *et al.*, 2017).

The rose shaped magnetic anomaly reaches to a maximum value of 214 nanoteslas (nT) in clear contrast to the local average values of the zone of only zero nT to 40 nT. (EMAG for Google, and NGDC-720 lithospheric magnetic model, http://geomag.org/models/). This is a characteristic of large impact structures (*cf.* Melosh, 1989; Osinski and Pierazzo, 2012).

In fact the Malvinas structure's positive magnetic anomaly is very similar in its numbers and shape characteristics to the one associated to the Chicxulub multi ring impact structure (200 kilometers in diameter) in Yucatan, Mexico, (Pilkington and Hildebrand, 2000; Rebolledo-Vieyra *et al.*, 2010; H. Lopez Loera, 2016, pers com., M. Rebolledo Vieyra, 2016, pers com.; M. Pilkington, 2017, pers com.).

Marine Seismic Reflection Lines

Eight marine seismic reflection profiles of this area are in possession of the Geco Prakla Schlumberger Geophysics Company, London, United Kingdom. They were completed and performed in the 1990 and are not very clear especially in the crystalline basement area.

The figure 2 shows a color map showing

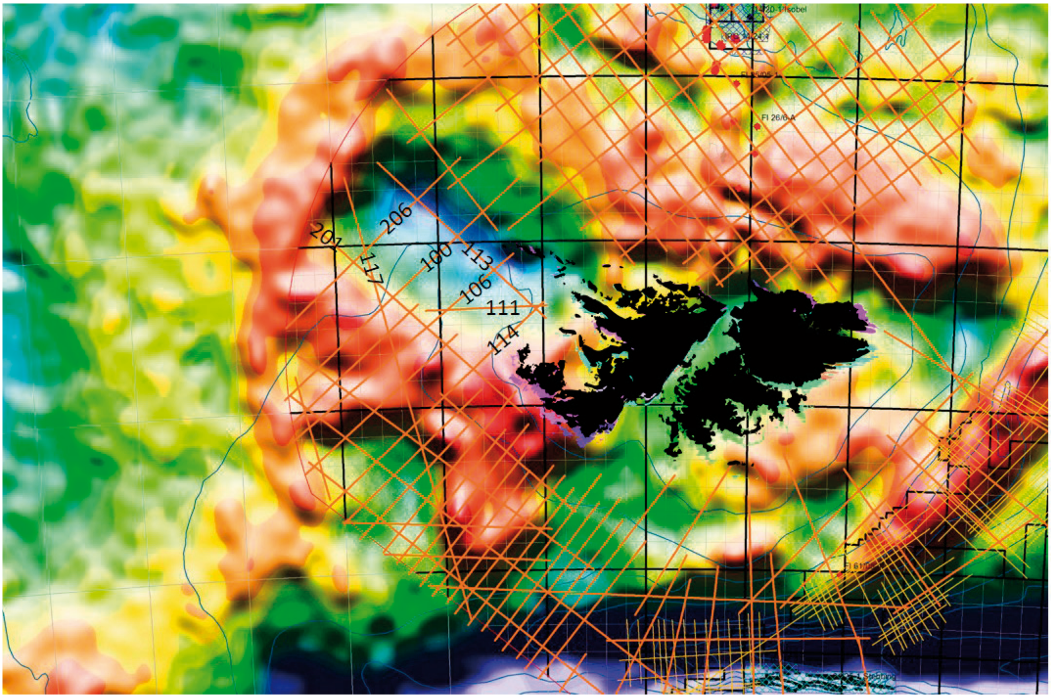

Figure 2 - It presents a color map showing the offshore geographic location of the Geco Prakla Schlumberger marine seismic reflection lines located in the area to the NW of the Gran Malvina= West Falkland island. These lines are showed here superimposed to the Bouguer gravity anomaly map of the area published by the British Geological Survey in 1998. Reproduced with permission.

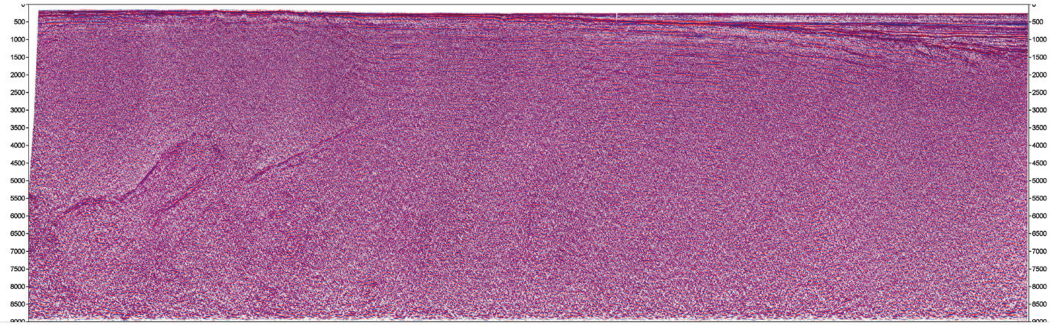

Figure 3 - Geco Prakla Schlumberger Marine seismic reflection line number 100 of the area to the NW of Gran Malvinas=West Falkland. Reproduced with permission from the Falkland Islands Government.

the offshore geographic location of the Geco Prakla Schlumberger marine seismic reflection lines in the area to the NW of the Gran Malvina= West Falkland island. These lines are showed here superimposed to the Bouguer gravity anomaly map of the area published by the British Geological Survey in 1998.

In 2017, we obtained copies with a permission to reproduce them in our publications from the Falklands Islands Government.

McCarthy *et al*. (2017), in their comment to our essay published in *TERRA NOVA* (Rocca *et al.*, 2017) supported and remarked the nonexistence of a large impact structure in the area by their interpretation of the structural geology of a part of the seismic line number 100.

It is interesting to note here that McCarthy *et al*. (2017) published only the upper left corner (SW extreme) of the entire seismic line 100.

Here we also present for the first time our basic structural geology interpretation of the whole entire Geco Prakla Schlumberger seismic line number 100.

The figure 4 notes the clear large Late Paleozoic (Late Permian?) basin in the North East extreme of the line and the deep large normal faults in the area to the South West (M. Rebolledo-Vieyra, 2018, pers com.; H. Lopez-Loera, 2019, pers com.).

This fits with an eroded large impact basin structure. One that was first eroded a bit and then completely buried by younger Mesozoic and Tertiary sediments. This interpretation of

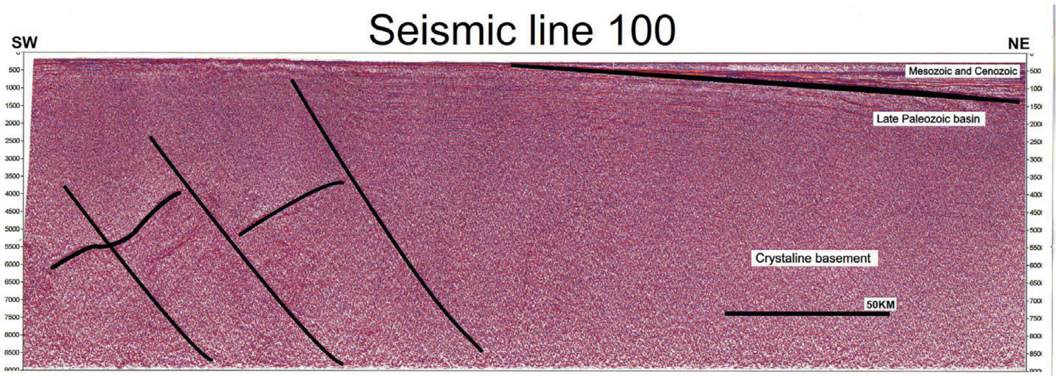

Figure 4 - Interpreted version of the Geco Prakla Schlumberger Marine seismic reflection line number 100 of the area to the NW of Gran Malvinas=West Falkland. Reproduced with permission from the Falkland Islands Government.

the seismic line 100 is very similar to the ones of the Chicxulub's impact structure showed in Figure 7 published in Gulick *et al.* (2013).

A large prominent regional erosional unconformity separates the Paleozoic strata from the younger Mesozoic and Tertiary sediments. It seems that at the Late Permian times highly erosive processes were active in the area (Platt and Philip, 1995). There was a worldwide event of high erosion at the end of the Permian times (Benton, 2008). The Malvinas area was not the exception (Platt and Philip, 1995).

We speculate that the possible Late Permian (?) Gran Malvina=West Falkland's impact basin structure was first eroded and then completely buried by younger sediments. It could be the remnant of a peak ring basin or even a multi ring basin structure.

New Gravity Anomaly Map

We have already made a detailed gravimetric analysis of the large negative anomaly located to the NW of Gran Malvina=West Falkland (Baez Presser *et al.*, 2019).

A very impressive new map of the Free Air Gravity anomaly was obtained from Dietmar Muller of University of Sydney, Sydney, Australia.

Note again the very impressive 250 kilometers wide crater-like negative gravity anomaly located to the NW of Gran Malvina= West Falkland island. Again, the numerical gravity values of this anomaly are close to the ones associated to the 200 kilometers wide Chicxulub impact structure in Yucatan, Mexico (Hildebrand *et al.*, 1991 and 1995; Grieve *et al.*, 2008).

This large gravity anomaly is no doubt associated with a low density area of a Late Paleozoic (Late Permian?) basin. It shows a minimum value of -30 milliGals (mGal) surrounded by at least one 250 kilometers wide roughly circular ring of positive values (maximum +50 mGal), (Rocca *et al.*, 2017) is typical of large impact structures (French, 1998; Osinski and Pierazzo, 2012) and not by far to the values of the gravity anomalies associated to the Mesozoic 200 kilometers wide Chicxulub impact structure in Yucatan, Mexico (*cf*. Hildebrand *et al.*, 1991 and 1995; Grieve *et al.*, 2008; Gulick *et al.*, 2013).

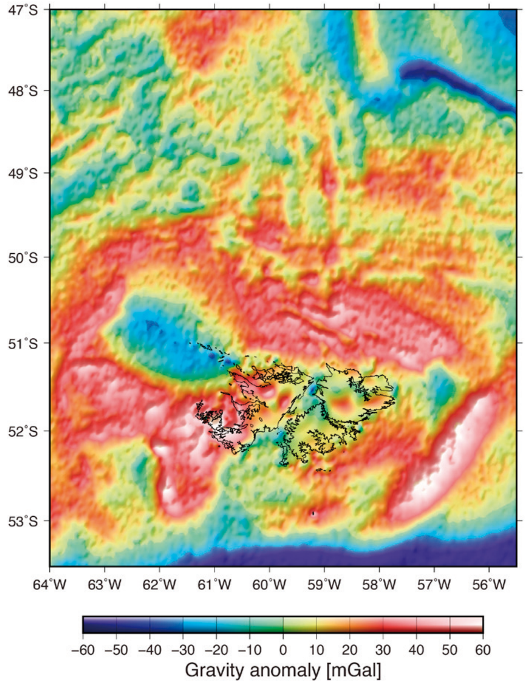

Figure 5 - Map of the offshore Free Air Gravity anomaly of the entire Malvinas=Falklands area. Source. World Gravity Map, Dietmar Muller (Univ. of Sydney, Australia).

New Magnetic Anomaly Map; *Rose of The Malvinas=Falklands*

We have obtained from Manuel Catalan (ROA, Spain) a new set of magnetic anomalies maps of the area to the NW of the Malvinas from the World Digital Magnetic Anomaly Map database, WDMAM.

Again the Eastern part of the gigantic

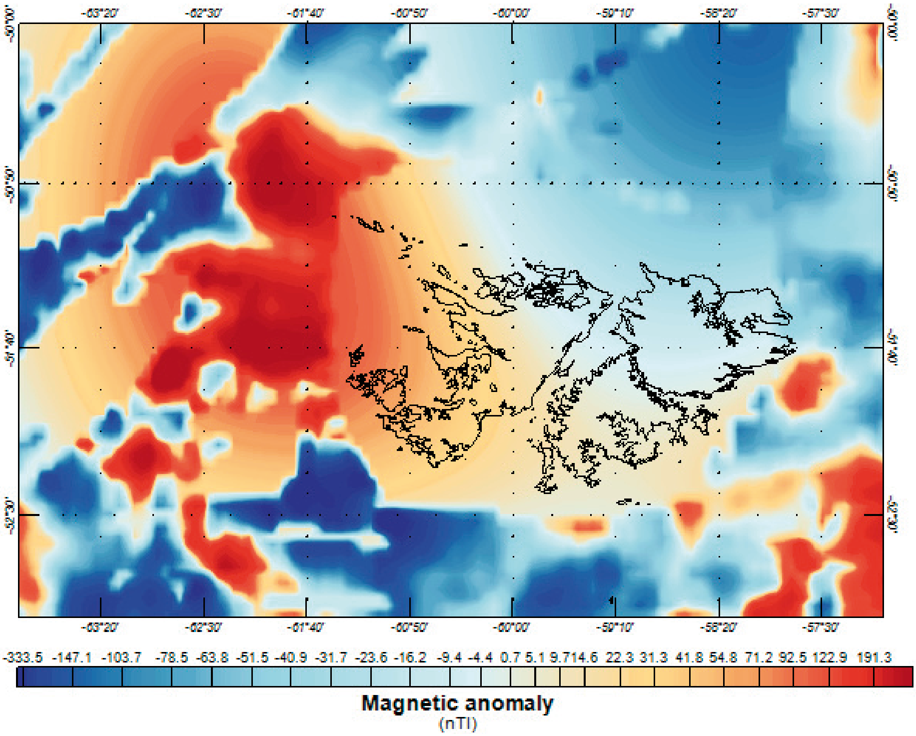

Figure 6 - Map of magnetic anomalies of the whole Malvinas=Falklands area. Areas seen in yellow have no available data. Note in red the Eastern part of the gigantic positive anomaly associated to the Late Permian (?) basin and located to the NW of Gran Malvina=West Falkland island. Source: Manuel Catalan, (ROA, Spain), WDMAM database.

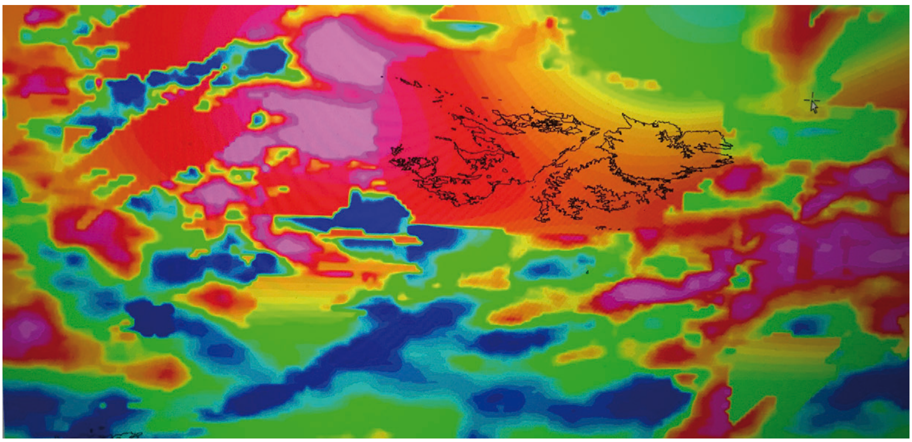

Figure 7 - A close up view of the map of magnetic anomalies of the entire offshore Malvinas=Falklands area. Note in violet the Eastern part of the 250 kilometers wide positive giant magnetic anomaly associated to a Late Paleozoic basin located to the NW of Gran Malvina=West Falkland island. Source: Manuel Catalan (ROA, Spain), WDMAM database.

250 kilometers wide positive anomaly (*The Rose of the Malvinas=Falklands)* is clearly visible in the area. The rose shaped magnetic anomaly reaches to a maximum value of about 200 nanoTeslas (nT) in clear contrast to the local average values of the zone of only low values (WDMAM database).

This is again the magnetic signature of large impact structures (*cf*. Pilkington and Hildebrand, 2000; Osinski and Pierazzo, 2012).

DISCUSSION

The existence of a Late Paleozoic giant 250 kilometers wide roughly circular gravity anomaly in the offshore area to the NW of the Malvinas=Falklands have been challenged by the British Geological Survey's geologists.

By using new gravimetric data the British Geological Survey's colleagues (McCarthy *et al*., 2017 and Stone and McCarthy, 2018) try to reject the existence of an impact event in the area. Instead of a roughly circular anomaly, a subtriangular Late Paleozoic sedimentary basin has been reported for the same area.

It is enigmatic to note that, so far, the only gravity anomaly map of the offshore area to the NW of Gran Malvina=West Falkland island that shows a triangular basin is the one published by McCarthy *et al.* (2017).

All the other available gravity anomalies maps published by the SEGEMAR (1997) the British Geological Survey's (Aldiss and Edwards, 1998's map) and in many of the internet geophysical databases (e.g., World Gravity Map -WGM2012 model, NASA TOPEX, etc.) show a roughly 250 kilometers wide circular anomaly there.

Concerning the magnetic "*Rose of the Malvinas=Falklands*"'s 250 kilometres wide positive anomaly it has been suggested that it could be the signature of a basic volcanic center of Jurassic age (D. Aldiss, pers com., 2016). Such a volcanic center, however, might be expected to create a large prominent positive gravity anomaly. In Cape Orford, the South Western extreme of the Gran Malvina=West Falkland island, an area with a large swarm of Mesozoic basic dolerite dykes (Richards *et al*., 2013) is associated with a small positive magnetic anomaly (Aldiss and Edwards, 1999). But that area also shows a prominent positive gravity anomaly (e.g., Word Gravity Map-WGM-database). On the other side, there is no large prominent positive gravity anomaly is visible in the entire offshore submarine area of the Late Paleozoic basin located to the NW of Gran Malvina=West Falkland island (SEGEMAR, 1997; World Gravity Map-WGM- database).

Old hydrothermal alteration activity in Devonian sandstones has been reported in the "neck" of the Steeple Jason island and it has been associated to the Late Paleozoic basin located offshore to the NW of the Jason islands (=Islas de los salvajes, Northwestern extreme of Gran Malvina= West Falkland island), (Aldiss and Edwards, 1999). The local occurrence of spectacular ferruginous staining along joints in Mid Paleozoic sandstones on the SW shore of Steeple Jason is possible evidence for the presence of a volcanic center (Aldiss and Edwards, 1999). This could well be evidence of a buried volcanic center in the area. However, another possibility is that, during the Mesozoic, basic intrusive volcanic rocks could have intruded as dykes and sills into the pre existing deep large normal faults placed in the crystalline basement of the hypothetical large Late Paleozoic impact basin structure. At the same time, hydrothermal activity is again a very good characteristic and proof of the existence of a very large impact structure (*cf*. Osinski and Pierazzo, 2012).

Any hypothetical volcanic center in that area would have been very large to create the 250 kilometers wide positive magnetic anomaly. However, the presence of a large, buried 250 kilometers wide impact basin structure can explain very well the co-occurrence of both a negative gravity anomaly and a positive magnetic anomaly in the same area (Hildebrand *et al.*, 1991; Grieve *et al.*, 2008; Gulick *et al.*, 2013; Rocca *et al.*, 2017).

Unfortunately, the youngest Late Paleozoic outcrop sedimentary strata located onshore in the Malvinas=Falklands islands are dated as Early to Mid Permian (Aldiss and Edwards, 1999; Trewin *et al.*, 2002). There are no outcrops of Late Permian or Permian-Triassic boundary sedimentary outcrops onshore in the islands to test the impact hypothesis.

This hypothetical large impact event could be in connection with the worst life mass extinction, the so-called "Great Dying", event in the history of the Earth at the end of the Permian times 252 Ma ago (Erwin, 2006; Benton, 2008; Rampino, 2017).

The recent geochemical report of the discovery of extraterrestrial 3 Helium isotopes in the Permian-Triassic boundary strata of Japan strongly supports the hypothesis of a large cometary/asteroid impact event at that time (Onoue *et al.*, 2019).

At present, the Late Permian's life mass extinction event has been associated to the huge and massive volcanic basaltic flood eruptions in Siberia, Russia (Erwin, 2006; Benton, 2008).

It is also very interesting to note here that at the Late Permian times (252 Ma ago) the Siberian basaltic floods, Russia, were located in the exact antipodal point of the Malvinas=Falklands possible impact basin structure. Was a strong Late Permian asteroid/comet impact event in the Malvinas=Falklands plateau (equivalent to an earthquake of Magnitude 12; Melosh, 1989) the origin of the massive eruptions in Siberia?

The powerful seismic waves would have traveled and propagated across the entire planet to then focus in the antipodal point of the Late Permian world. A process now called as "impact induced antipodal volcanism event" (Rampino, 2017).

A recent work by a team in Berkeley University, USA, supports the cause-consequence effect connection between the Chicxulub impact structure in Yucatan, Mexico, and the massive basaltic volcanic eruptions in the Deccan Plateau in India 66 Ma ago. Chicxulub in Mexico and the Deccan plateau in India were in the antipodes at the K-Pg event times (Richards *et al.*, 2015).

Did the same cause-consequence effect connection happen in the case of the Malvinas=Falklands structure and the Siberian basalts 252 Ma ago? It is possible that the impact in Malvinas= Falklands have triggered the massive and catastrophic volcanism in Siberia.

CONCLUSIONS

The new available geophysical information again supports the existence of a possible very large (250 kilometers wide) Late Permian(?) complex impact structure in the offshore area to the NW of Gran Malvina=West Falkland island.

The presence there of a buried 250 kilometers wide impact basin structure can explain the co-occurrence of both a negative gravity anomaly and a positive magnetic anomaly in the same area (Hildebrand *et al.*, 1991; Grieve *et al.*, 2008; Osinski and Pierazzo, 2012; Gulick *et al.*, 2013; Rocca and Baez Presser, 2015; Rocca, 2016; Rocca *et al.*, 2017). However, without drill cores samples taken from the Late Paleozoic basin itself this case remains inconclusive.

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