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MODELED MEGA IMPACT STRUCTURES IN PARAGUAY: II- THE EASTERN REGION

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Resumen.- Este trabajo representa los avances en la tarea de levantar información sobre el fenómeno de impacto meteorítico en el Paraguay Oriental. Se realiza una apreciación corta y preliminar, basada en la geofísica (gravimetría, magnetometría y espesor cortical) acompañada de alguna información sobre la geología (de superficie) y petrografía microscópica que evidencian metamorfismo de impacto (PFs, PDFs, vidrio diapléctico) en cuatro cráteres de impacto meteorítico: Negla con ~80-81 km-D., Yasuka Renda con ~96 km-D., Tapyta con ~80 km-D. y San Miguel con ~130-136 km-D. Donde un quinto, Curuguaty con ~110 km-D. fue reconocido con base a la información geofísica -probable cráter de impacto meteorítico. Las unidades impactadas varian desde el basamento cristalino Arcaico/Proterozoico Inf.-Sup. a sedimentos del Pérmico. Los modelados cráteres de impacto meteoritico son cortados por diques de rocas toleíticas y/o alcalinas del Mesozoico, cubiertos por lavas toleíticas del Mesozoico (Negla, Yasuka Renda, Tapyta y Curuguaty) y uno de ellos fue cubierto (en parte) por sedimentos del Grupo Caacupé (Siluro/Devónico). En las cinco estructuras mencionadas se delata la presencia de mineralizaciones o indicios de la presencia de mineralizaciones como oro, diamantes, REE. Cráteres de impacto meteorítico modelados que están parcial a marcadamente erosionados.

Palabras clave: *modelado de nuevos megacráteres de impacto, Paraguay-Oriental.*

Abstract.-We report here the discovery and study of several new modeled large impact craters in Eastern Paraguay, South America. They were studied by geophysical information (gravimetry, magnetism), field geology and also by microscopic petrography. Clear evidences of shock metamorphic effects were found (e.g., diaplectic glasses, PF, PDF in quartz and feldspar) at 4 of the modeled craters: 1) Negla: diameter:~80-81 km., 2) Yasuka Renda D:~96 km., 3) Tapyta, D: ~80 km. and 4) San Miguel, D: 130-136 km. 5) Curuguaty, D: ~110 km. was detected and studied only by geophysical information. Target-rocks range goes from the crystalline Archaic basement to Permian sediments. The modeled craters were in some cases cut by tholeiitic/alkaline rocks of Mesozoic age and partially covered by lavas of the basaltic Mesozoic flows (Negla, Yasuka Renda, Tapyta and Curuguaty). One of them was covered in part by sediments of Grupo Caacupé (age: Silurian/Devonian). Some of these modeled craters show gold, diamonds, uranium and REE mineral deposits associated. All new modeled large impact craters are partially to markedly eroded.

Key words: *new modeled large impact craters, Eastern Paraguay.*

As part of an ongoing scientific research project to discover new impact craters in Paraguay we detected a potential complex impact structure of 20-22 kilometers –the cráter Negla- in Departamento de Concepción/Amambay (Eastern Paraguay), see Presser *et al*. (2015). More recent studies of gravimetry, magnetism, field geology and petrography showed that the modeled Negla impact structure is larger than previously thought reaching to 80- 81 kilometers in diameter. We also found clear evidences of shock metamorphic effects at this site, (Table 1)

Table 1. General characteristics of the modeled new impact craters in the Easten of Paraguay. Topex* Sandwell et al. (2014).

Structure/Crater Probable-P Most probable-MP	**Negla** MP	**Yasuka Rendá** MP	**Curuguaty** P	**Tapyta** MP	**San Miguel** MP
Aproximate Diameters (Km)	~80-81	~96	~110	~80	~130-136
Coordinates (centre)	Lat. -22.473052° Long. -56.731518°	Lat. -23.117514° Long. -56.005541°	Lat. -24.744502° Long. -55.016714°	Lat. -26.214763° Long. -55.882364°	Lat. -26.515128° Long. -57.193174°
Gravimetry	Free-air-gravity (Topex*) transformed to architecture/depth of the target rock determines an apparent central peak eroded. Its crest (rim crest) partially preserved is well defined (half-moon shaped) at the end SE. (Fig. 1) Crustal thickness ~1000 m	Free-air-gravity* transformed to architecture/depth of the target rock determines a well-defined central peak, surrounded by an expressive collar depression which, in turn is surrounded by a ridge partially preserved. (Fig. 1). Crustal thickness~1750 m.	Free-air-gravity* transformed to architecture/depth of the target rock determines a well-defined central peak, surrounded by an expressive collar depression which, in turn is surrounded by a ridge partially preserved. (Fig. 1). Crustal thickness~1750 m ~1100 m.	Free-air-gravity* transformed to architecture/depth of the target rock determines a well-defined central peak, surrounded by an expressive collar depression which, in turn is surrounded by a ridge partially preserved. (Fig. 1) Crustal thickness~1750 m ~1400 m.	Free-air-gravity* transformed to architecture/depth of the target rock determines a well-defined central peak, surrounded by an expressive collar depression which, in turn is surrounded by a ridge partially preserved. (Fig. 1); it is also well determined in Bouguer gravimetry- "bull's-eye" pattern (Fig. 1) Crustal thickness~1750 m l ~1900 m.
Magnetometry (EMAG2)	Bi-polar Anomaly very simple separated in two highs at N (37-51nT) y lows at S (-33nT).	Bi-polar Anomaly asymmetric with respect to the central peak. Highs of 67nT at S and lows of -18nT at NW .	Bi-polar Anomaly with highs of 4nT next to the central peak and lows of -33nT al SE and -35nT at NNW of the crest..	Bi-polar Anomaly. High of 4nT at the central peak and lows of -22nT at SE and -61nT at W.	Bi-polar Anomaly. High of -4nT at the Se rim of the peak and lows of -84 nT at NE and -79 nT at SE .
Remarks	Complex impact crater with a very eroded central peak .	Complex impact structure with a central peak and an incipient peak ring. Partially eroded.	Complex impact structure of the central peak type.	Complex impact structure of the central peak type. Slightly eroded.	Complex impact structure of the central peak type. Apparently it is very eroded.
Expossed rocks	Diamictite (proximal ejecta), pegmatite (quartz-feldspar), gneiss-máfic, kimberlític sediments. Impact breccias lamprofídic (lamproita/kimberlita) of quartzitic matrix.	Impact breccia rich in lamprofídic (lamproite/kimberlite) fragments and with a quartzitic matrix.	No data.	Lithified sandstone , impact glass (meteorized), quartzite.	Quartzite, migmatites, granites, rhyolitoids, pegmatites (quartz-feldespar) and pebbles of quartz.

Table 1 (end). General characteristics of the modeled new impact craters in the Easten of Paraguay. Topex* Sandwell et al. (2014).

Structure/Crater Probable-P Most probable-MP	**Negla** MP	**Yasuka Rendá** MP	**Curuguaty** P	**Tapyta** MP	**San Miguel** MP
Shock metamorphism 1-Quartz, 2-Feldspar, 3-others	PFs and PDFs 1, 2.	PFs, PDFs, impact glass 1.	No data.	PFs, PDFs, diapléctic glass, impact glass (totaly meteorized) 1, 3 (macro-grains of pyrrotite).	PFs, PDFs, diaplectic glass. 1, 2.
Impacted unit/s	Metamorphic basement Archaic/Proterozoic Inf. and probable Carboníferous sediments.	Permian sediments and occasional kimberlitic (age 145 Ma. ?).	Permian and also some Trias/Juras sediments.	Permian/Triassic sediments.	Archaic/Proterozoic Matamorphic basement Inf./Granitoides of 550 Ma.
More recent formations Infilling sediments of the crater's basin	Tholeitic diabase dykes of Suite Alto Paraná cut the infilling sediments of the crater.	Tholeitic diabase dykes of Suite Alto Paraná cut the infilling sediments of the crater. Alkaline intrusion also cut the crater (dates 143-110 Ma). And also areas covered by E-SE lavas of Suite Alto Paraná.	Covered at the E by lavas of the Suite Alto Paraná.	Tholeitic diabase dykes of the Suite Alto Paraná cut the infilling sediments of this crater. Covered at the E by lavas of the Suite Alto Paraná.	Sediments of Grupo Caacupé (Ord./Silu.) fill the central basin of the crater
Observations	Outcrops of mega-breccias (Fig. 2); faulted crystalline basement; deca metric mega-blocks turned, folded and faulted calcareous sediments Au nuggets (Presser unpublished data), Kimberlites/lamproites with diamonds (F/ex. *pink-fancy) and alluvial diamonds*.	Faults next to the central peak. Strong anomalies in REE (eg, Nb 3-4%). Lamproites/kimberlites with diamonds and gold nuggets in alluviums.	Gold in alluviums; High concentration of ?Ti in soil of lavas of Suite Alto Parana.	Numerous outcrops of massive impact breccias. Anomalies of KIM, diamonds in alluviums. Explotation of Uranium in sediments of the Permian at the WSW crest of the crater.	Breccias outcrops, (Fig. 2); A strongly faulted area in the crystalline basement. Basament Mega blocks turned Anomalies of Au (8-288 ppb). High concentrations of Fe associated with meta sediments at the city of San Miguel-Itayurú.
References	Presser et al., (2012); Presser et al. (2015); Presser (2016); This work.	(Anschutz Corporation unpublished data, 1980/1982); Presser et al. (2012); Eby & Mariano (1992); Gibson et al. (1995); This work.	Vane Minerals plc, Branch office Paraguay in 2004; Grup CIC Resources INC 2014.	Bitschene, 1987; Rex Mining in 2003; Uranium Energy Corp. 2015/2016 (http://www.uraniumenergy.com/projects/paraguay Access 04/2016); Presser (2016); This work.	Cordani et al. (2001); Marchetto (1997); This work.

(Presser, 2016).

More recently as a part of the scientific project "Caracterización de los Recursos Hídricos para la Gestión de la Protección de la Reserva de la Biosfera del Bosque Mbaracayu (Departamento de Canindeyu) y de la Reserva Natural Tapyta (Departamento de Caazapá) Paraguay" (ONGAgua/CONACYT 2015-2016)), new gravimetric studies, field geology and petrographic studies carried us to the discovery of a new large complex very probable impact structure: the Tapytá structure in the Dpto. de Caazapa, Diameter ~80 km. (Presser, 2016).

In this work we are going to make a brief report of both the above mentioned structures. Negla and Tapyta with special attention on their geophysical data (gravimetry and magnetism) and the field geology characteristics. We are also going to give results from new petrographic studies under the microscope. We also report here 3 additional large structures for the Eastern region of the country (Fig. 1).

This present new report is the result of a multi-disciplinary work from the researchers-team at ONGAGUA, researchers at Facultad de Ingeniería de la Universidad Nacional de Asunción, researchers of the planetary geology in Argentina, and others.

MATERIALS AND METHODS

The gravimetric studies were performed from satellite data:

1- "Global or regional gravity grids (2'x2') derived from the World Gravity Map (WGM2012 model). Quantities included: complete Bouguer and Isostatic (Airy-Heiskanen) anomalies, surface free-air anomaly (Molodenski), gravity disturbances produced by the Earth's surface masses (topographic relief, oceans, inners seas and major lakes and polar ice caps)" http://bgi.omp.obs-mip.fr/activities/Projects/world_gravity_map_wgm (Access in 06/2014 to 04 2016).

2- "Gravity V23.1." (Sandwell, *et al*., 2014) free-air - 1 in 1 minute http://topex.ucsd.edu/cgi-bin/get_data.cgi (Access at early 2015).

For the 3D modeled (3D and others) of the basement/target-rock (i.e. architecture/depth of the target rock) we used the straight equation -Depth (m.) = -3306.3+(144.1*G) Where G is the value of free-air. (Presser, 2014).

For the modeling of the crustal-thickness we used the straight equation -H (km.) = -31.85 - ((0.1291 * Boug) +(0.0002089 * $Boug^2$)) of Assumpção, *et al*. (2013). Calculations were performed in txt. and Excel. The equation that produces the values in excess of the order of ~7000 meters with relation to the global values which can be extracted from CRUST 1.0 A New Global Crustal Model at 1x1 Degrees: http://igppweb.ucsd.edu/~gabi/crust1.html#visualization (Access in 03/2016).

The magnetic behavior was inspected from EMAG2 with resolution of 2-minutes-of-arc and the world magnetic anomaly at altitude 4 kilometers above sea level. In the satellite compilation we used X, Y and Z values taken form http://geomag.org/models/emag2.html (Access 05/2015): "EMAG2 (Version 2.0) ASCII grid of the magnetic total intensity at 4km above WGS84 ellipsoid. This version was produced without directional gridding. Therefore, it has much sparser coverage but reflects more closely the actual measurements".

Petrographic sample analysis searching for evidences of impact shock metamorphic effects were observed under the Vintage Leitz MOP Polarizing Ore Petrographic Pol. Microscope. (40 to 400X).

RESULTS AND DISCUSSION

The preliminary observations of the 5 probable/most probable mega impact craters (**5-P/MPMIC**) from the Eastern Paraguay are shown in Table 1 and shown in Figure 1 ; i.e.: Probable crater: Curuguaty (**C**), (this work) and Very Probable crater: Negla (**N**), (Presser, *et*

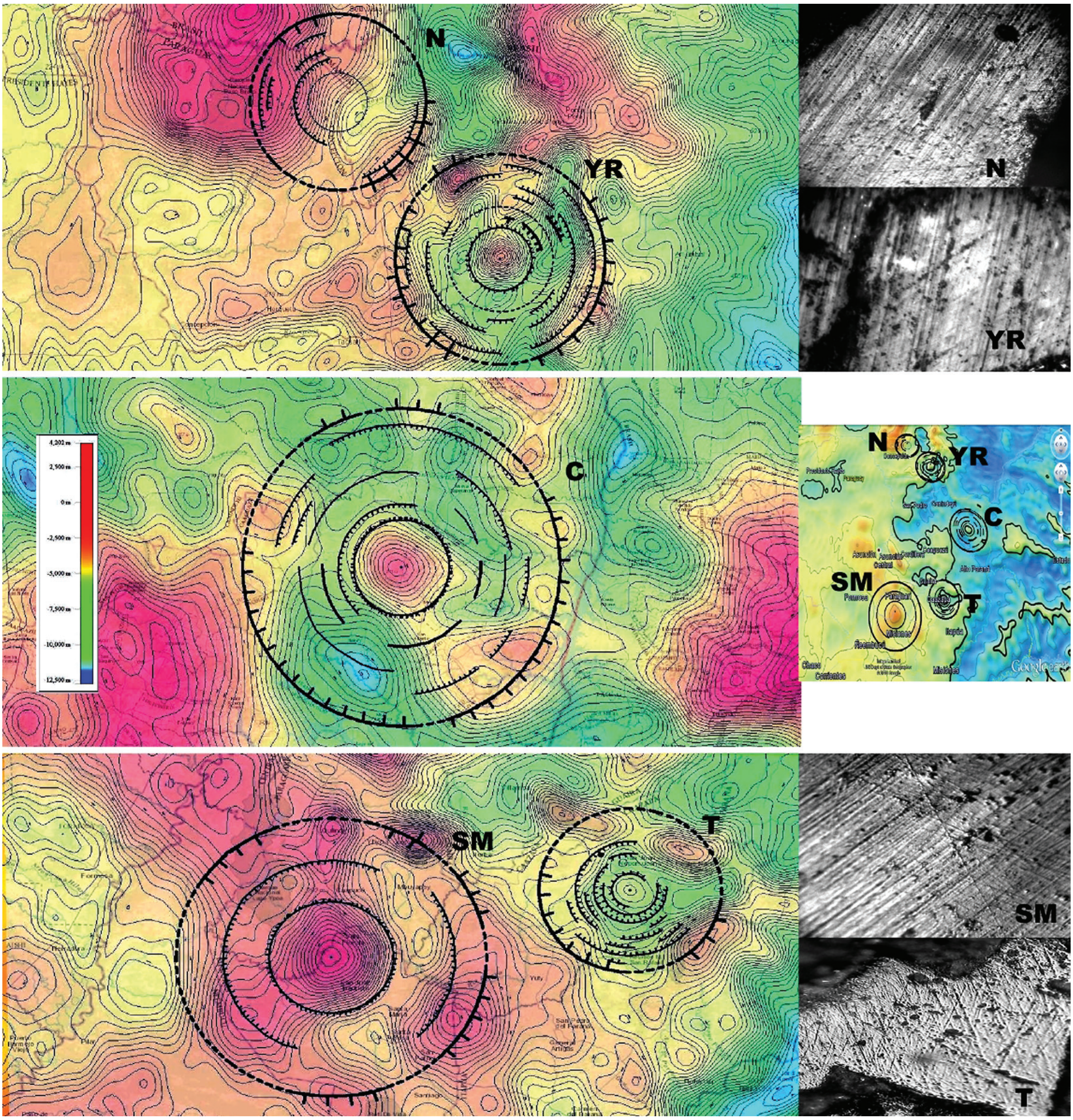

Figure 1. Gravimetric configuration (Gravity V23.1." (Sandwell, et al., 2014)) (free air gravimetry architecture/depth of the target rock) of the modeled Eastern Paraguay mega impact craters: **N** and **YR** (upper figure), **C** (middle figure), **SM** y **T** (lower figure). Fault rings and their dipping orientation were drawn on the images. To the right of the images the microscope views of the Planar Deformation Features (PDFs) are shown, in quartz grains from lithified sediment in **N**, in the quartzitic breccias from **YR**, and in quartzites from **SM** and **T**.

al. 2015, Presser, 2016), Yasuka-Rendá (**YR**), (this work), Tapyta (**T**), (Presser, 2016) and San Miguel (**SM**), (this work); Diameters (kms.): **N** ~80-81, **YR** ~96, **C** ~110, **T** ~80 and **SM** ~130-136; Co-ordinates (center); Gravimetric and Magnetometric Characteristics; Remarks**;** Type of rocks exposed; Shock metamorphic effects evidences **;** target rock; and others.

The **5-P/MPMIC** were identified from the modeling of their gravimetric parameter (free air, free-air-gravity transformed to architecture/depth of the target rock; Bouguer gravity values and Bouguer-gravity to crustal thickness-data). Gravimetric parameter that show the characteristics of complex impact structures: a clear central peak surrounded by a annular trough and a circular rim-crest (usually partial/markedly blurried)(Fig. 1) -where **SM** show the clear bull's-eye patterns (Melosh *et al*., 2013) (visible both in the free air as also in the Bouguer maps) and in free-air-gravity transformed to architecture/depth of the target rock). At **N** the central peak is completely eroded. It was found that the **5-P/MPMIC** show a Chicxulub-like configuration (free-air transformed to architecture/depth of the target rock as well as the crustal-thickness).

The **5-P/MPMIC** show in aeromagnetic data from EMAG2 the typical bi polar anomaly of complex large impact craters as mentioned in Morgan & Rebolledo-Vieyra (in Osinski & Pierazzo (2013)).

The **MPMIC N** and **T** were field recognition weighted and , **YR** and **SM** were only preliminary field recognition (Fig 2 and 3). The probable crater **C** was only characterized by geophysical analysis.

Shock metamorphic effects were found as quartz's diaplectic glass, PFs y PDFs (PF = Planar Fractures, PDF = Planar Deformation Features , both in quartz and feldspar) in the rocks from the crystalline basement (gneisses, migmatites, granitoids, pegmatites, rhyolitoids and quartzites) of **N** and **SM**; and impactite

Figure 2. Landscapes from the area of the modeled mega impact craters. **Upper view, Left: N**: mega blocks of sediments (mega breccia) next to the SW of the rim crest (SSW of estancia Trementina); **Upper view, Right:** Cerro Guazú central peak of **YR**: wall of sediments. **Lower View, Left:** Central peak of SM: shocked quartzites (with very abundant diaplectic glass) in the town hall quarry of Itá Yurú. . **Lower View, Right:** South rim of the central peak at **T**: the rim crest is visible in the horizon.

Figure 3. Examples of rock exposed at the modeled mega impact craters. **Upper view, Left:** N: reddish diamictite (proximal ejecta) with abundant millimeters to centimeters angular to rounded clasts -with levels a centimetric of polimigct breccia, (road in the way to Bella Vista Norte, Amambay). Shocked grains of quartz (PDFs) were identified in these rocks. **Upper view, Right:** Central peak of crater YR: Impact breccia rich in lamprophyric clasts with a quarztic matrix. Collected at the NW rim of Cerro Guazú. Impact glass and PDFs were identified in the quartz grains from this rocks. **Lower view, Left:** Central peak of SM: brecciated and shocked quartzites (with abundant diaplectic glass) from the town hall quarry of Itá Yurú. **Lower view, *Right:*** Area close to the S of crater rim crest T: "impact glass"-rich breccia (very weathered) collected form the area around the town of Tavaí.

rocks (e.g., impact breccias, diamictites, rounded and impacted cobbles and pebbles, shocked quartzites, etc,) of **YR**, **T** and **SM**. So the **5-P/MPMIC** will be considered as **Modeled Impact Crater.**

The impacted units varied from old crystalline basement of Archaic/Proterozoic Inf.-Sup. Age (**N** y **S**) to the Permian sediments (**YR**, **C** and **T**)? and lamprophyric rocks of their inferred ages 146.7 ± 12.8 Ma, -see Eby & Mariano (1992)(YR).

Some of the modeled mega impact craters are cut by tholeitic dykes (Suite Alto Paraná –Mesozoic= 140 to 135 Ma. see Bitschene, 1987; Gibson, *et al*., 1995 -**N**, **YR**, **C**, **T**) and/or by alkaline rocks intrusions (e.g. at the alkaline complex Cerro Sarambi with110.8 ± 10.8 to 85.4 ± 4.6 Ma and by the shonkinite intrusions of 114.0 ± 15.8 Ma. at Cerro Guazú (ass seen in Eby & Mariano, 1992) –in **YR**. As well as, of them are also partially covered with the tholeiitic lava flows (Suite Alto Paraná)(**YR**, ?**C** and **T**). **SM** is covered in part by the sediments of Grupo Caacupé (Siluric/Devonic).

It is interesting to note the presence of gold in **N**, **YR**, **C** and **SM**; and/or the presence of diamonds in lamproite/kimberlite pipes or in alluvium at **N**, **YR** and **T**; the presence of Rare Earth Elements (REE), connected with the shonkninite intrusion of Cerro Guazú (Anschutz Corporation unpublished data) in YR and uranium minerals at the SW of the **T** (Uranium Energy Corp. 2015/2016).

All these **5-Modeled Impact Crater** are partially to highly eroded (Table 1).

Further new scientific research is being done: 1-at **T** by the scientific team of ONGAGUA -petrography, field geology and hydrogeology; 2-petrography works of the impactites collected at **SM** by Prof. Dr. Rogelio Daniel Acevedo and the Planetary Geology Team of Argentina; 3-shock metamorphic effects studied in much more detail in the **N** samples.

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