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PERIDOTITIC GEOTHERMS OF THE RÍO DE LA PLATA CRATON ARCHON-CORE

Geotermas peridotíticas del núcleo arcón del Cratón del Río de La Plata

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Abstract. At the Rio de la Plata Craton archon-core environment were inferred, based on 1D Vs profiles (on 208 numbers of points), of the peridotitic geotherms. Values for the archon-core environment, it was estimated 38.5 to 40 mW/m^2 in its central northern portion and southern portion and in its edges/southern portion 40 to 42 mW/m^2. Geotherm values that allowed estimate LAB between 243 to 237 km depth (northern portion) and 225 to 213 km depth (southern portion). The same 1D Vs information allowed recognizing for this geothermal environment the depth of the graphite-to-diamond phase transition, finding that it is located at ~135 km depth. So, projecting 70-90 km (southern portion) to 102-108 km (northern portion) thickness of the "diamond window" for the Rio de la Plata craton archon-core. "Diamond window" thickness very close to those of the Kalahari archon craton where the highest grade of diamond deposit is the Kimberley with 200 cpht. Thus, it is estimated that diamonds grades that could be expected, for eventual diamond deposits, be close to that of the of Kimberley diamonds deposits in the archon core of the Río de la Plata craton.

Key Words. Archon-core of Río de la Plata craton, geotherms, "diamond window", diamond-grade.

Resumen. En el entorno del núcleo arcón del Cratón del Río de la Plata se infirieron, con base a los perfiles Vs 1D (en 208 números de puntos), los gradientes geotérmicos peridotíticos. Los valores para el entorno del núcleo del arcón se estimaron de 38,5 a 40mW/m^2 en su parte norte central y sur de 40 a 42mW/m^2. Valores geotérmicos que permitieron estimar LAB entre 243 a 237 km de profundidad (porción norte) y 225 a 213 km de profundidad (porción sur). La misma información de Vs 1D permitió reconocer para este entorno geotérmico la profundidad de la transición de fase de grafito a diamante, encontrando que está ubicada a ~135 km profundidad. Entonces, proyectando 70-90 km (porción sur) a 102-108 km (porción norte) de espesor de la "ventana de diamante" para el núcleo arcón del cratón del Río de la Plata. El espesor de la "ventana de diamante" se asimila al cratón de Kalahari donde el mayor grado de depósito de diamantes es Kimberley con 200 cpht. Por lo tanto, se estima que podrían esperarse grados en diamantes, para eventuales depósitos de diamantes, próximos al del depósito de diamantes Kimberley en el núcleo arcón del cratón Río de la Plata.

Palabras Clave. Núcleo arcón del cratón de Río de la Plata, geotermas, "ventana del diamante", grado de diamante.

INTRODUCTION

Based on the behavior 1D of the S-waves expressed as dVs% of the model TX2011 *vs* PREM (*cf*. http://ds.iris.edu/dms/products/emc/horizontalSlice.html), on the different kimberlites and lamproites in the archon (Archeozoic), proton (lower to medium Proterozoic), and tecton (Proterozoic medium to superior) lithospheric mantles, in the Paraguay DDEE, Presser (2019a) affirmed that all diamond mines with a high degree of diamonds (greater than 100 cpht) occurred only in archon lithospheric mantles: *i.e*. lithospheric mantle with very high velocity (dVs% greater than 4.3-4.4 about the PREM in 1D profiles, between 100-175 km depth) (Figure 1). When this is taken as a global model at 150 km depth of 2D seismic tomography of the dVs% model TX2011 and in the delimited domains superior/equal to 4.3 dVs% and the area covered by all the (rich and world class) diamond mines (of kimberlites

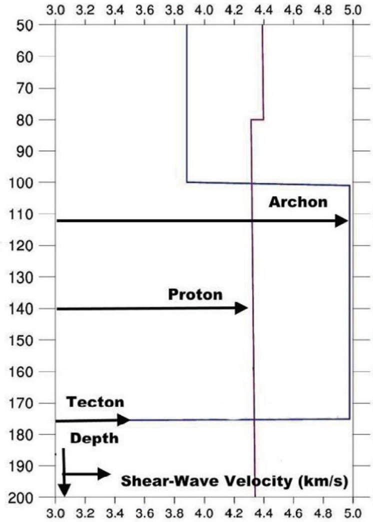

Figure 1 - 1D of the S-waves (expressed as dVs% of the model TX2011 *vs* PREM) on the different tectonic environments of cratonic lithospheric mantles: archon, proton and tecton. Archon lithospheric mantles: can be identified by very high velocity =dVs% greater than 4.3-4.4 in relation to the PREM (between 100-175 km depth); from Presser (2019a), Presser and Kumar (2020). Seismic information source from the Iris page.

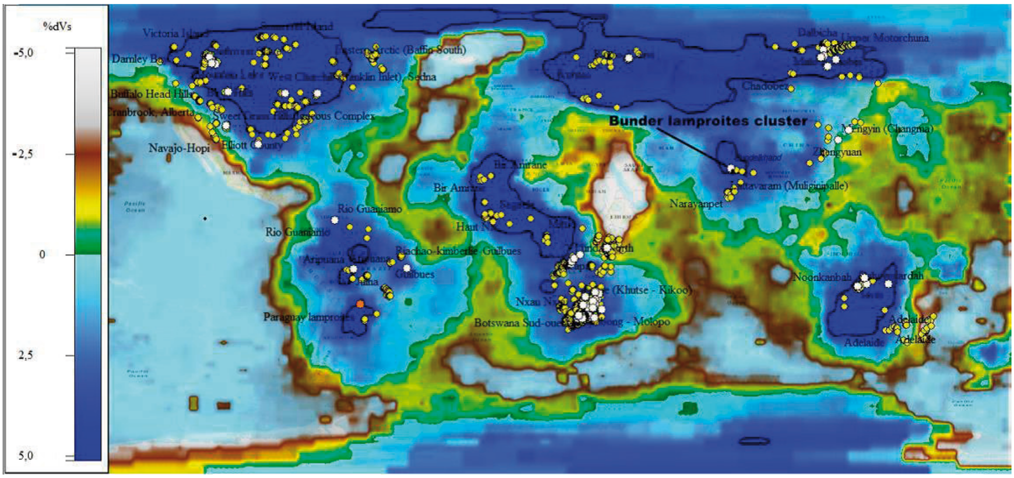

Figure 2 - Global (seismic configuration) Archon lithospheric mantles here delimited by iso-lines on a global map of % dVs at 150 km depth of the model TX2011. All the diamond mines (white balls), more especially those with greater than 100 cpht, are located within the delimited Archon lithospheric mantles (from Presser, 2019a; Presser and Kumar, 2020). Area that is understood to be undisturbed over time and that could represent the core of the craton; this is archon-core. This refers to a lithospheric mantle that may or may not coincide with that found by surface geology in shield areas. Seismic information source from the Iris page.

and lamproites) the criterion shows good agreement (Presser and Kumar, 2020) (Figure 2).

As proposed by Presser (2019b), as well as Presser and Kumar (2020), based on the Garber *et al*. (2018), 1D S-wave seismic allows estimation of surface heat flow or geotherms (or "paleo-geotherms") from an area of lamproites (and kimberlites, etc.) intrusions. And consequently, project the potential of these intrusions for the formation of diamond deposits (Presser and Kumar, 2020). Based on this geothermal inference criteria, this work presents, with the help of estimation on 208 numbers of points (1 in 1 degree), the geotherm of the Río de la Plata craton archon-core (core as outlined by Presser 2019a, b) and its potential diamond grade is analyzed for eventual diamond deposits.

MATERIALS AND METHODS

For the determination of the geotherms, it starts from Figure 3, specifically in this

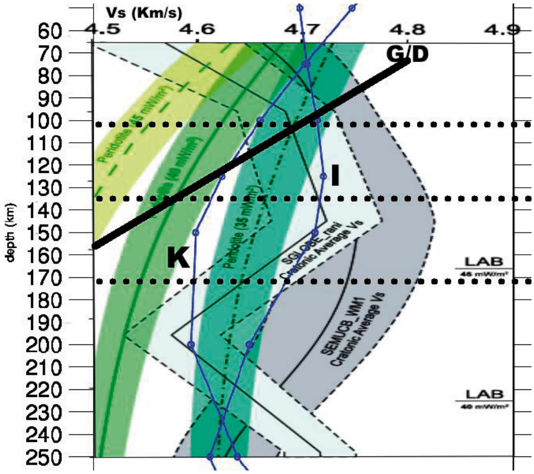

Figure 4 - Vs profiles for end-member cratonic peridotite, and diamond from Garber *et al*. (2018), with partial modification, (as in Figure 3) for Kimberley-diamonds deposits (**K**) concave profile and International- diamonds deposits (**I**) - convex profile. The convex 1D format is more typical to associate with areas with very high grade of diamond deposits (such as in Yakutia craton environments). When the concave 1D format is more frequent than medium grade diamond deposits (such as in Kalahari craton environments). Legends as in Figure 3. 1D seismic information source from the Iris page.

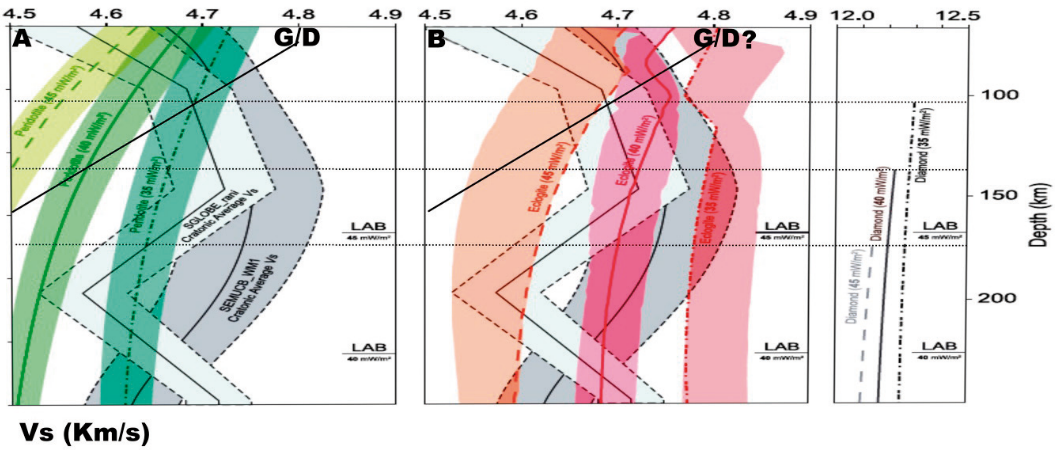

Figure 3 - Vs profiles for end-member cratonic peridotite, eclogite, and diamond from Garber *et al*. (2018), with partial modification. **A**, for peridotites, and **B**, for eclogites. Geotherms end-member: 45, 40 and 35mW/m^2; **G**, graphite and **D**, diamond; LAB: Lithosphere Asthenosphere Boundary (for 45 and 40mW/m^2). On the G/D plane for eclogites it is not known if it corresponds as indicated in Figure B.

work, Figure 3A or peridotitic geotherms will be taken into consideration. Thus, online starting from the http://ds.iris.edu/dms/products/emc/depth_profile.html (Iris page), the 1D profile is obtained using the Moulik and Ekstrom (2014) model. The profile obtained for the given coordinate is then carefully overlapped with Figure 3A, as shown in Figure 4. The 1D profile, if applicable, will fit end members geotherms 45 or 40 or 35mW/m^2 or between two of them, thus it will have been estimated with great approximation the geotherm of that coordinate.

It is mentioned again at 208 points around the Río de la Plata craton archon-core Arqueozoic to Proterozoic craton (Siegesmund *et al.*, 2018) environment. Thus, was estimated, the geotherms at 150 km depth. The Moulik and Ekstrom (2014) model itself, which shows 3-degree spacing, the software used in Iris (http://ds.iris.edu/dms/products/emc/depth_profile.html) would achieve a very acceptable extrapolation of the data.

RESULTS

As indicated in the methodology, the punctual-geotherm was estimated for 208 points surrounding the archon-core of Río de la Plata craton environment (Figure 5), points that representing estimated geotherm at 150 km depth as the routine showed, as an example, in Figure 6.

Figure 6 compares the geotherm of diamond deposits in the Kalahari craton

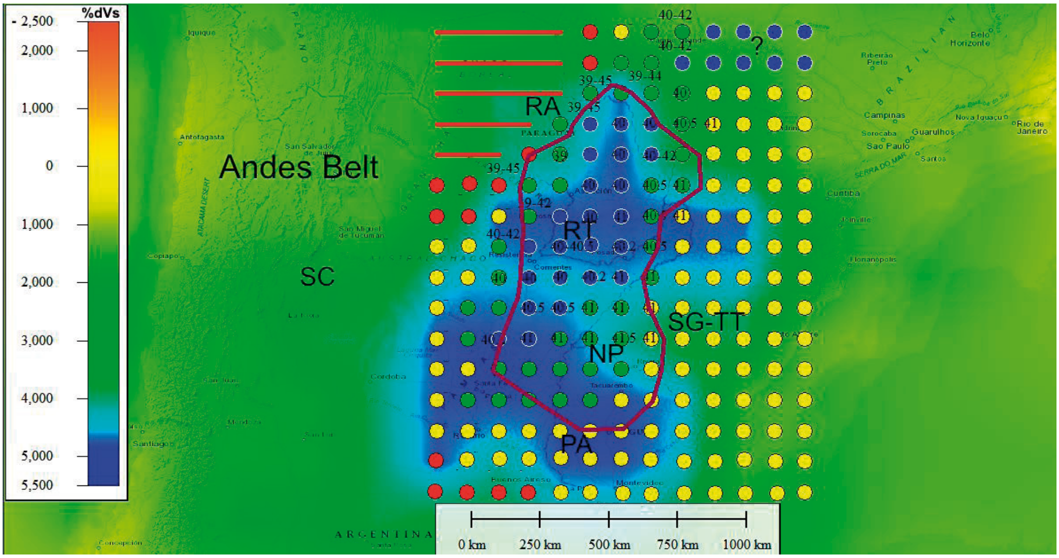

Figure 5 - Río de la Plata craton archon-core (1250X 558/520 km in its length by wider widths -purple line from Presser *et al*., 2017; Presser, 2019a, b) with estimated general geotherm. Cratonic archon geoterm as balls of blue/green, cratonic archon /post-archon as yellow balls and mobile belts in red balls/lines. The most commonly referred surface tectonic units are indicated; as **PA**, Piedra Alta terrain; **SR**, Sierra de Córdoba; **NP**, Nico-Pérez terrain; **SG-TT**, Sao Gabriel Tacuarembó terrain; **RT**, Río Tebicuary uplift; **RA**, Río Apa. More information on these shield domains can be found widely at Siegesmund *et al*., (2018) and Teixeira *et al*., (2020). Information is released on a global map of % dVs (value originals multiplied by a thousand) at 150 km depth of the model TX2011. Seismic information source from the Iris page.

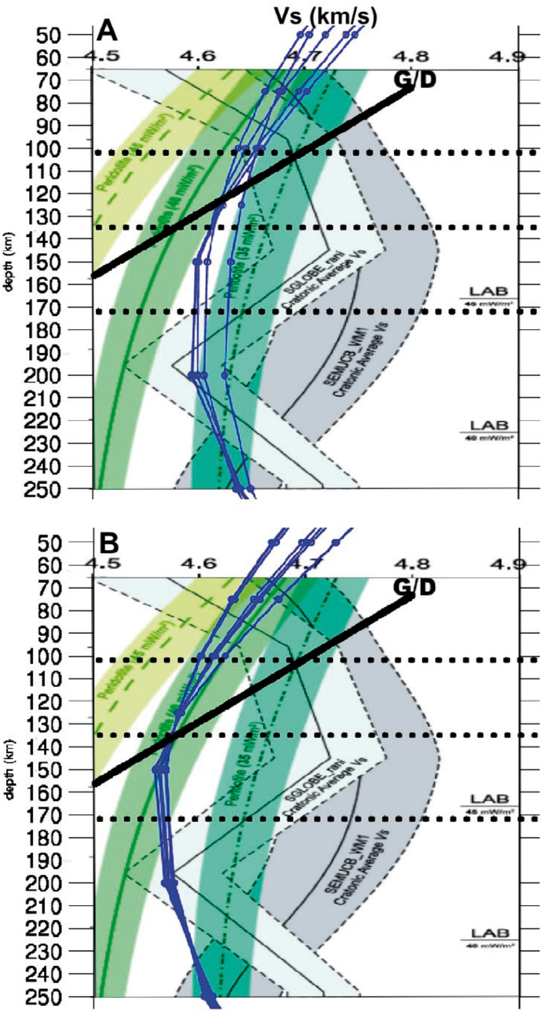

Figure 6 - Vs Concave profiles for end-member cratonic peridotite, and diamond from Garber *et al*. (2018), with partial modification, (as in Figure 3 and 4) for some Kalahari diamonds deposits (**A**) and some diamond-bearing Paraguay lamproites (**B**). Legends as in Figure 3. The diamond deposits studied in A: Orapa, Premier, Venetia, Kimberley and Loxton. 1D seismic information source from the Iris page.

environment (A) and the geotherm of some diamond-bearing lamproites/lamprophyre pipes from Paraguay in the archon-core of Río de la Plata craton environment (B). As we can see, the Kalahari craton environment geotherm and the archon-core of Río de la Plata craton environment geotherm are concave-format. In the first case, the geotherm indication would be between ~40 to 38mW/m^2 crossing the G/D line between the ~120 to 125 km depth. While in the second geotherm indication would be around ~40 to 38.5/39mW/m^2 crossing the G/D line in the ~135 km depth. The convex 1D format suggests, deducted from Garber *et al*. (2018) interpretation, that in-depth there would be a decrease in the degree of mineralization in diamonds; while the concave 1D format suggests otherwise and/or a root formed by eclogites/eclogites with diamonds.

Figure 5 as can be seen shows zoning of the geotherms obtained; this is geotherm-values from ~38.5/39 to 40mW/m^2, in their center, they are bordered by geotherm-values between 40 and ~41mW/m^2, which in turn are outlined by geotherm-values between ~41 and 43mW/m^2. Geotherm-values of the cratonic limit (≥45mW/m^2), more typical of the area of mobile belts, are marked more in the fringe to the west. Low geotherm-values are properly found within the archon-core of the Río de la Plata craton environment.

According to Garber *et al*. (2018), the LAB (lithosphere-asthenosphere boundary) for the geotherm 45mW/m^2 is ~170 km; for 40mW/m^2 is ~230 km (between both a difference of 60 km). Where for 35mW/m^2 in the opinion of Garber *et al*. (2018) they are greater than 300 km (however, based on the same reasoning, it is believed that it could be 35mW/m^2: 290 km).

Garber *et al*. (2018) do not make clear the role of eclogite masses in the root of the craton and its role in the delimitation of the LAB. So if taken into consideration the peridotitic cratonic mantle geotherm we can expect to next to the coldest area (~38.5/39mW/m^2) in the archon-core of Río de la Plata craton environment between ~243-237 km LAB; while in the south,

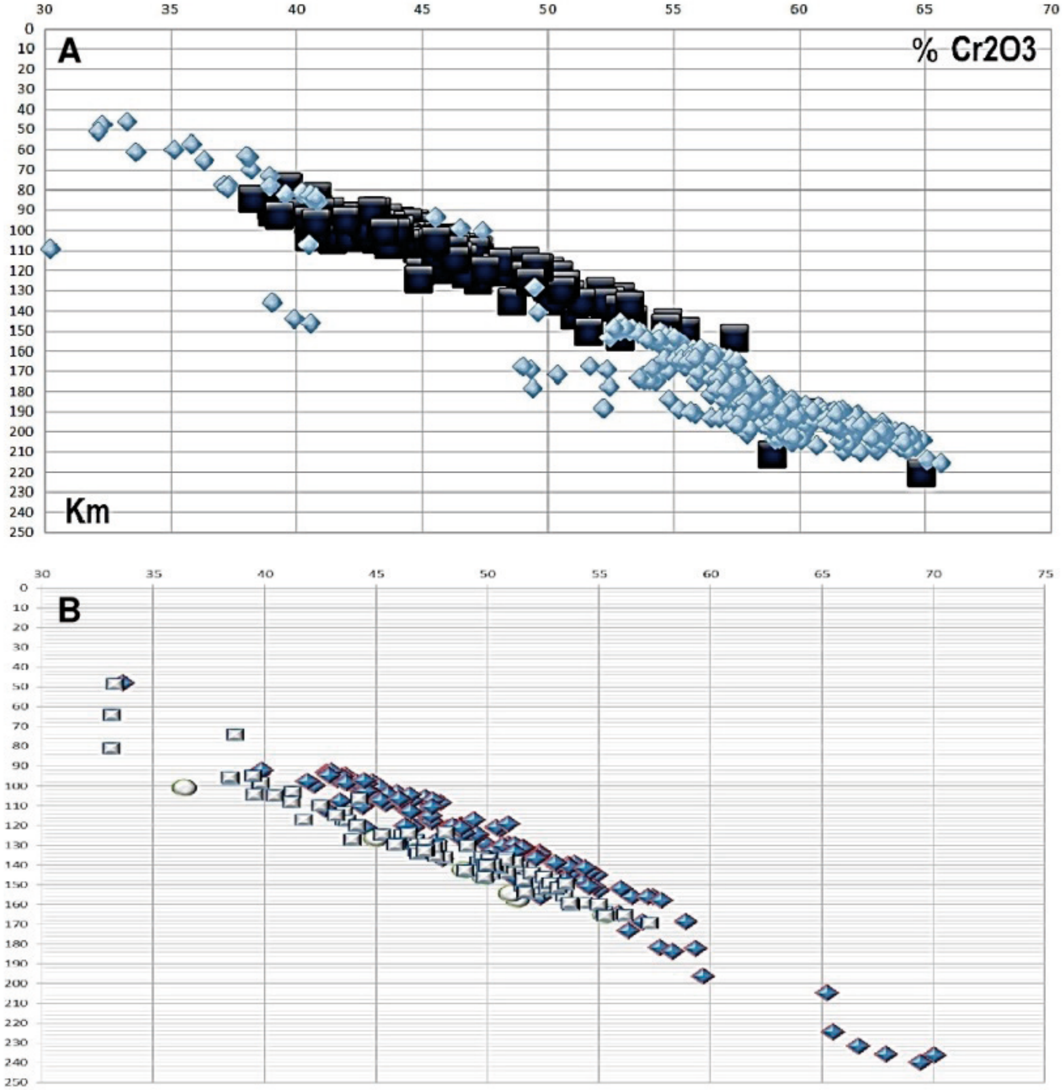

Figure 7 - Pressure expressed in km *vs* content in Cr_2O_3 of chromites in lamproites/lamprophyre ducts of the Kalahari craton and the Río de la Plata craton archon-core. In **A** chromites from two lamproites different clusters in the northeast of Kimberley (Presser, 2019c). In **B** chromites from three lamproites/lamprophyre from Paraguay: Ymi-1 (La Colmena), Ybytyruzú-cluster, and NNE Dpto. Concepción. Here the formation pressure (Kbar), for individual chromite grains, is represented in km of formation depth from the formula: Cr/Cr+Al * % Cr_2O_3 (Presser, 1998) were to transform into km the Kbar. obtained is multiplied by 3.64.

which is somewhat hotter (~40 to 42mW/m^2) between ~225-213 km LAB, and by the same path, concerning the Kalahari craton environment between ~260-225 km LAB.

ANALYSIS AND CONCLUSION

In the previous item, it was commented that for the Kalahari craton a LAB of ~260-

225 km could be estimated and that for the coldest part of the archon-core of Río de la Plata craton environment at ~243-237 km of LAB. Figure 7 gives an approximation of the calculated pressure of formation of individual chromite crystals; pressure transformed into formation depth from Presser (1998) empirical calculation formula: Kimberley/Loxtondal area greater depth estimated being 220 km (Figure 7A) and Paraguay-area greater depth estimated being 240 km (Figure 7B). Both data, more accurately the Paraguayan data, project a very good agreement for the LAB depth estimated using the depth (from the formation pressure calculation) estimated for chromite grains and the estimated from of the calculation projected

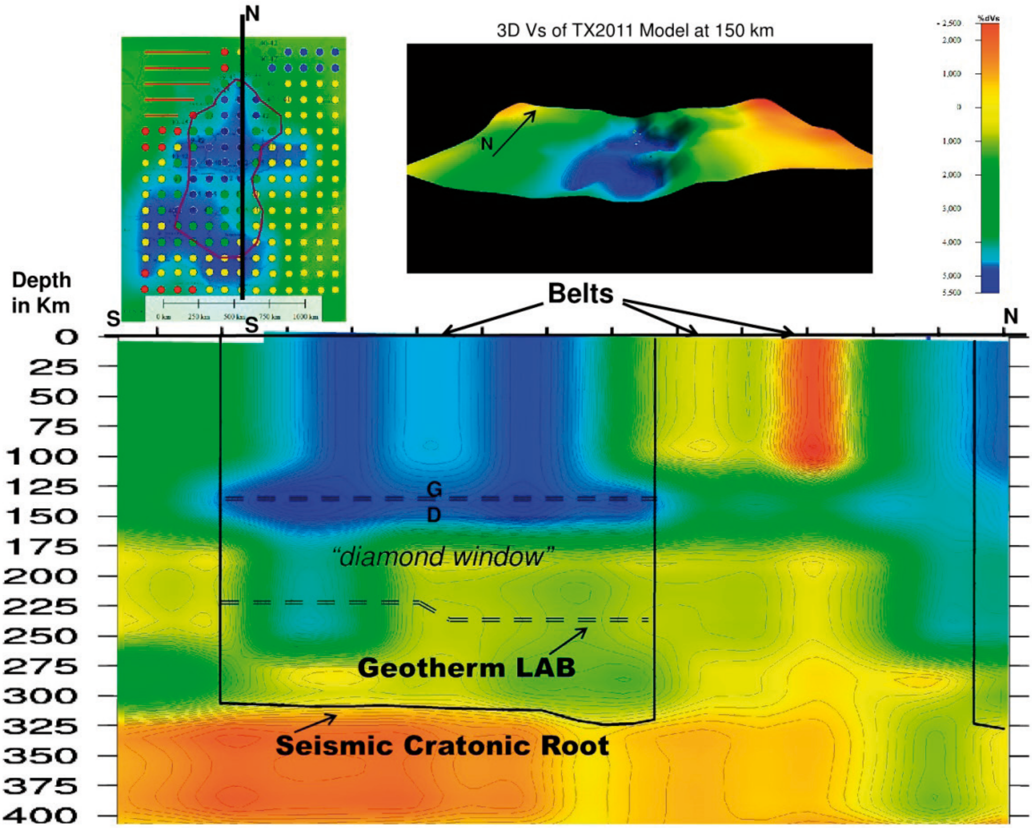

Figure 8 - N-S seismic tomographic (of % dVs of the model TX2011) profile (-56 W between -15 to -35 S) which cuts off part of the Río de la Plata craton archon-core. The seismic tomographic profile evidencing two deep archon-root domains with different depths; where North (the coldest slice in Figure 5) portion is deeper than the portion of the South (the warmest slice in Figure 5). Between both is evidence a paleo-belt (% dVs something fast that it is intuited that of the Archeozoic). Other belts as the north the belt in red (% dVs very slow) represents the Neoproterozoic Araguaia belt (for example, Fonseca *et al*., 2004) and the belt in yellow (% dVs slow) surroundings of the Paleoproterozoico Río Apá terrains (*cf*. Teixeira *et al*., 2020). In the profile, the "diamond window" with the depth of the LAB was outlined as discussed in the text. **G**. Graphite. **D**. Diamond. Seismic information source from the Iris page.

by the geotherms. Geothern's calculations for the Kalahari craton, by the current P-T method, can be verified that they oscillate around the ~40mW/m^2 (Artemieva, 2011, and references; Garber *et al*., 2018).

In this way, it is believed that what is represented in Figure 5 would be something that can be taken as valid. Thus, and when observing the geotherm values contained within the archon-core of Río de la Plata craton environment, as previously commented, shows zoning of the geotherm obtained with cold values (~38/39 to 40mW/m^2) in the northern portion while the southern portion is somewhat warmer (~40 to 42mW/m^2). This archon-core zoning is better understood when looking at Figure 8, an N-S tomographic profile (-56 W between -15 to -35 S) evidencing two archon-root domains with different depths; where the North (coldest) portion is deeper than the portion of the South (the warmest). Between both, we evidence a paleo-belt (it is intuited that of the Archeozoic).

The difference in depth of the roots of the archon-core between the northern portion and the southern portion has implications in the geology of the diamond, partly as already discussed in the results, that is:

- in the northern portion, the geotherm values (~38.5/39 to 40mW/m^2) suggest, based on what is shown in Figure 6B, crossing the G/D line between in the ~135 km depth and ~243-237 km the estimated depth of the LAB is located; =108-102 km thick "diamond window".

- in the southern portion, the geotherm values (~40 to 42mW/m^2) suggest, also based on what is shown in Figure 6B, crossing the G/D line between in the ~135 km depth and ~225-213 km the estimated depth of the LAB is located; =90-78 km thick "diamond window".

For a quick comparison, again is brought to this the Kimberley area, in the Kalahari craton, that crossing the G/D line between in the ~125 km depth and ~260-225 km the estimated depth of the LAB is located =135-100 km thick "diamond window". Here the diamond deposit, so far found, with the highest grade in diamonds is the Kimberley pipe with 200 cpht (Field *et al*., 2008; Presser, 2019c).

Through the conventional P-T method Dymshits *et al*. (2020) estimated the (paleo) geotherm for the Upper Muna kimberlite field (Siberian craton) a ~34–35mW/m^2 surface heat flux, 225–230 km lithospheric thickness, and 110–120 thick "diamond window". In the Upper Muna kimberlite field, the lithosphere thickness is almost similar to the values obtained for the high-grade Udachnaya (~205 cpht) and Mir (~444 cpht) pipes from the Daldyn and Mirny fields, respectively (Dymshits *et al*., 2020; Garanin *et al*., 2014; Garanin, 2019).

If taken into consideration the comparisons of the potential diamond grade of the diamond-deposits based on geotherm (Presser and Kumar, 2020; Dymshits *et al*., 2020), it could be concluded that the archon-core of Río de la Plata craton (in the northern portion) would project diamond deposits (lamproites and kimberlites) with diamond grade below, but very close to, those from the Kimberley cluster (200 cpht). However, Dymshits *et al*. (2020) comment that all pipes in the Upper Muna field have low diamond grades (<90, in cpht), although the lithosphere thickness is almost similar to the values obtained for the high-grade Udachnaya and Mir pipes from the Daldyn and Mirny fields, respectively. And they end by saying that, other factors have affected the diamond grade of the Upper Muna kimberlite field.

The other factors that have affected the diamond grade could be evidenced, for example, in the careful and meticulous analysis of the 1D Vs profiles (such as those presented in Figures 3, 4, and 6). Garber *et al*. (2018) reviewed various geophysical and petrologic constraints on the nature of cratonic roots (seismic velocities, lithology/ mineralogy, electrical conductivity, and gravity) and explored a range of permissible rock and mineral assemblages that can explain the high seismic velocities; concluding that, these constraints suggest that diamond and eclogite are the most likely high-Vs candidates to explain the observed velocities. So it is believed that if in a cratonic region with a similar geotherm the diamond deposit (lamproite or kimberlite) the 1D Vs profiles if show differences (as well as subtle), throughout the estimated "diamond window", in the speed, it would be an indication of differences in the potential diamond grade in its primary sources. And here it is considered convenient to note that comparisons should always be between 1D Vs profiles of the same format: concave and convex as in Figure 4. Thus, it is believed that the geotherm found or estimated for a lamproite/kimberlite cluster would be a first approximation towards the potential diamond grades in a diamond deposit; nothing more.

Other possible anomalous factors that have affected the diamond grade in deposits in the same geotherm environment are discussed in Presser and Kumar (2020).

In the southern portion, the estimate of the diamond grade in eventual diamond deposits probably ranges from 100 cpht to below-grade what is projected in the northern portion. As the contribution in diamonds that could come from eclogites was not taken into account, it is believed that the commented potential diamond grade may be lower than the eventual real of the diamond deposits from archon-core of Río de la Plata craton environment.

In the archon-core of Río de la Plata craton environment the northern portion is cut by rifts/grabens, for example the Asunción rift (Degraff, 1985; Drueker and Gay, 1987). The Asuncion rift is invaded by hundreds of alkaline rock conduits from Mesozoic (K-rich to ultrapotassic, *cf* Bitschene, 1987; Presser, 1992 and 1998; Comin-Chiaramonti *et al*., 2017) to Tertiary (sodic, *cf* Comin-Chiaramonti *et al*., 2017). It is difficult to reconcile a rift inside a craton archon-core, usually a thick and rigid core that would not be simple to break and, therefore, allow the shortening of the lithosphere. The formation of impact craters causes the loss of crustal thickness and consequently, the deep cracking of the crust/mantle, sometimes causing distensional structures like grabens/ rifts-type (Presser, 2019b). In the southern part of the central portion of Asuncion rift (graben), the San Miguel impact crater occurs; impact structure where a significant decrease in crutal thickness was estimated due to the effect of impact (Presser *et al*., 2016). Despite this, the Río de la Plata craton archon-core environment would not have disturbed the geotherm (Figure 5 and relates). Yet it is in this northern portion of the Río de la Plata craton archon-core that a series of conduits of diamond-bearing lamproites and diamond-bearing calk-alkaline lamprophyre has been cited (Presser, 1992, 1998, 2016, 2019b; Presser *et al*., 1999; Presser *et al*., 2016). While the southern portion of the archon-core of Río de la Plata craton remains almost unexplored.

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