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Olie-2 (Olievenput) diamond-bearing pipe anomaly in Boshof district, South Africa

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Diamonds and Diamond Geology, Incommon Igneous Rocks

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ABSTRACT

At the end of 2014, around the so-called Loxtondal Orangeitic (now called Kaapval-type lamproites) cluster, in Boshof district, two circular anomalies (~540 to ~1100 meters in diameter) were identified by Landsat Satellite Images and interpreted as being of "kimberlites" pipes; probable anomaly which were referred to as Olie -1 and Olie-2. Subsequently, 100 kg of soil samples (horizon A/B) were taken for each of these anomalies. From them there was a high concentration of indicator minerals (IM): olivine, garnets (violets, reds and oranges), chromites, ilmenites, rutile, frosting tourmaline, zircon and among them some crystals of micro and macro diamonds. The high concentration of IM on Olie-2 led to focus the work on it. IM of Olie-2 was burned in HFl and by caustic fusion what contributed about 86 macro (<1 mm) and micro diamonds. The previus works contributed to raising the interest of some diamond geology groups that took new samples that provided electron microprobe analysis of hundreds of chromites and hundreds of garnets: chromites; picro-cromites, and G-9-G-10 garnets. The calculated pressure of the formation of chromites and garnets of Olie-2 released in the information of seismic Vs-1D and tomography (Model TX2011). It would allow more adequately to reproduce these two minerals generated in the facies of diamonds and separate them from those generated in facies of graphite. A task that would allow a better approach to the diamond potential of this anomaly studied. It was found that in Olie-2 chromites of diamond facies and garnets (G-9 and G-10) are very representative. For this time the study of the lithospheric cratonic mantle (Archon), through of the commented seismic Vs-1D and tomography (Model TX2011) on the Loxtondal cluster (Olie-2)/Kimberley-area setting allowed to estimate the surface heat flow as being approximately 37.5 mW/m2 = 280 km depth of cratonic root (or LAB). Environment in which the highest reference diamond grade is the Kimberley pipe with 200 cpht; and so, for this reason, a similar diamonds-grade could be expected on the Olie-2/potential associated pipes-area.

1. Introduction

Traditionally, until today, there are 2 rocks source of primary diamond deposits; the kimberlites and the lamproites.
The diamond deposits in kimberlites of greater degree in diamonds are in Russia (*cf.* Garanin et al., 2014 and Garanin, 2019). And the diamond deposit in lamproites of greater grade in diamonds is hosted by the Argyle pipe in Australia (*cf.* Roffey et al., 2018 and references). As can be seen in the reference books, on this special and in-communal type of alkaline rocks, the Kimberlites were subdivided into Group I (Archetipe) and Group II or orangeites (Mitchell, 1986; Mitchell & Bermang, 1991 and Mitchell, 1995). Diamond deposits at Orangeites are known almost exclusively in South Africa (*cf.* Field et al., 2008; Wit et al., 2016 and references); Fig. 1. Orangeites were recently relocated to the lamproite group =kaapvaal type lamproite (Scott-Smith, 2018). Loxtondal “kimberlites”cluster, that is a cluster of orangeites (Field et al., 2008) or more properly of kaapvaal type lamproite cluster, is located about 20-30 km to the NNE of famous

Kimberlitic Kimberley pipe (Big Hole). Loxtondal kaapvaal-type lamproite clustert comprises a set of dykes and pipe, some of them being small diamonds deposits. This work focuses on a new occurrence, in recognition process, that was identified in 2014 (Olie-2, Presser, 2015); that is considered as part of Loxtondal cluster. Following, will be comments on his work over the past few years and will conclude with some lines that refer to its potential as a diamond deposit. Work initiated as a response to a requirement of the manager of Brookfields PGM, Diamonds, Gold & Coal Explorations in 2014.

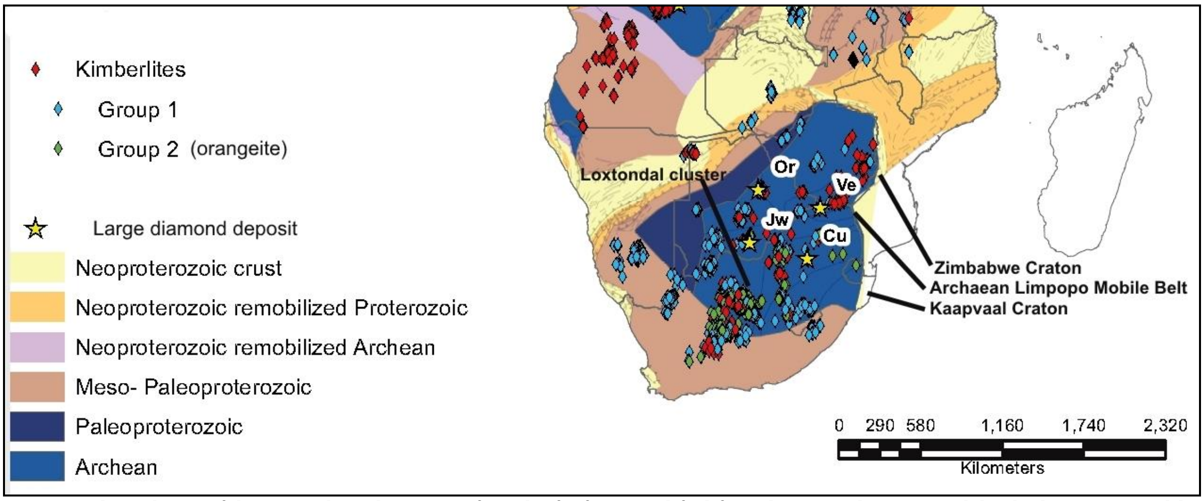

Fig. 1. Geological map of the Precambrian basement of South of Africa (modified from de Wit et al., 2016) with kimberlites Group 1 (blue) and Group 2 (green) and some -large diamond deposit: Cu =Cullinan, Jw =Jwaneng, Or =Orapa, Ve =Venetia. The approximate position of the Loxtondal cluster (former Group 2 kimberlite or orangeite and now referred to as Kaapvaal-type lamproite) is also indicated.

2. Material and Methods

2.1. Methodology

Targeting:
Pipes anomaly targets area were selected from Landsat 4/5 (1990) satellite image combined with previous structural studies.
Soil sampling:
Soil samples were taken (100 Kg for each point; ~A/B Horizon, in the coordinates previously indicated by Landsat pipes anomaly) then washing, digging and screened. Following this, samples were sent to SGS laboratory in Johannesburg. All samples heavies concentrated with Bromoform resulting in heavy mineral concentrates:
Weight
Olie 1 = 256grams
Olie 2 = 108grams.
After the petrographic observation, both samples were subjected to partial dilution (soluble silicates)
in concentrated HFl (relation sample 10%, acid 90%) for 5 days. This process diluted 100% olivine, much of garnets, some ilmenites, spinels and all present pyroxene. The resulting residue was observed to separate diamonds.

Seismic data (1D-Vs and %dVs-tomography) were extracted from:
http://ds.iris.edu/dms/products/emc/horizontalSlice.html (Access in June to July 2019).
Indicator Sorting:
Indicators were sorted with 10-80 magnification stereo microscope under artificial light. “Kimberlitic” garnets, olivine, Cr-diopside, chromites, ilmenites, tourmalines (Charles Fipke crater-facies tourmalines), sapphire, rutile, ilmeno-rutile, zircon, Cr-diopside and diamonds were taken and notified. A parameter for the freshness or proximity of indicator grains to their source was not applied in the form of a Sphericity Index; this is because the samples were collected from the potential “kimberlitic” pipe soil. The author based on their experience and study (unpublished) found that the sphericity in many mineral grains -rather is due to a magmatic abrasion. Yet in garnet grains was taken into consideration the Sphericity Index.
Positioning:
Coordinates were logged in Garmin e TRex 30 hand model GPS with and accuracy of 5 to 3 meters. Coordinates were drawn from Google Earth images and also in the software Global Mapper 19 and 20.

2.2. Geology

Loxtondal cluster is positioned above Archean basement of the Kaapvaal Craton, a known and well identified thick and cold craton (e.g., James & Fouch, 2002) (Fig. 1 and 2). Archean or Archon craton that is an ideal tectonic environment for the occurrence of diamond-bearing "kimberlites" that could be high diamonds grade (pinched comments from Presser, 2019a).

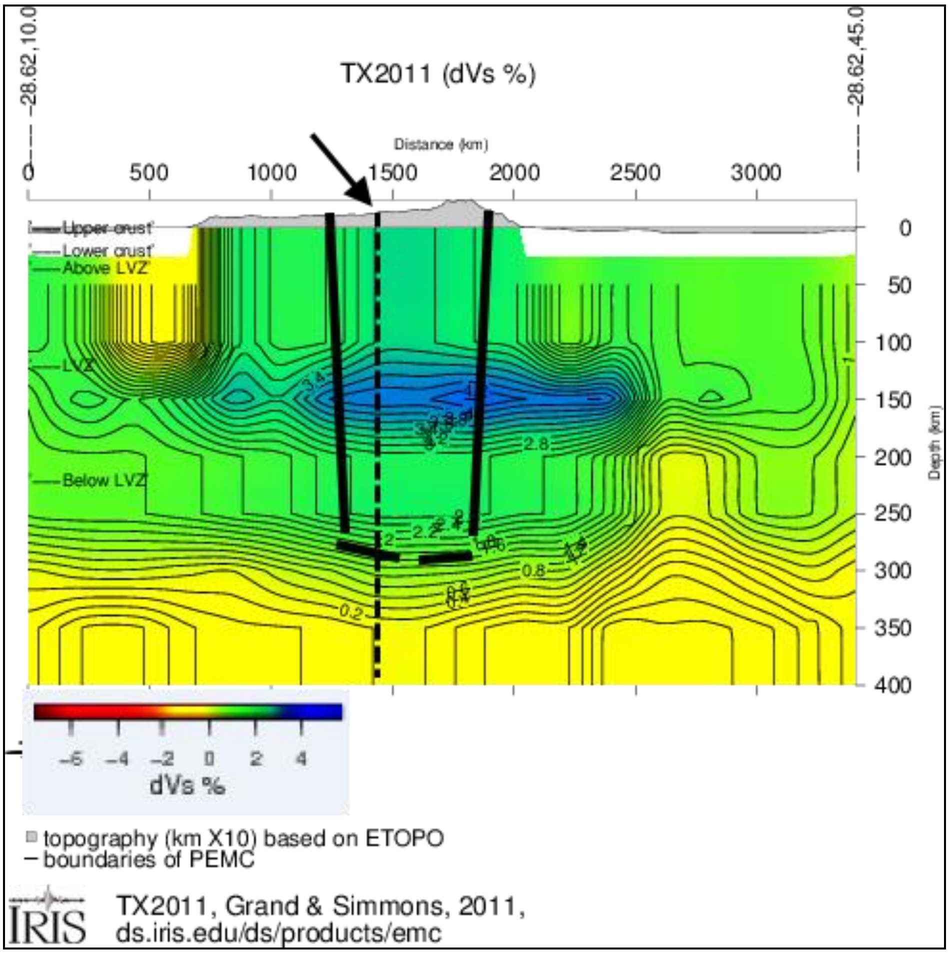

Fig. 2. Kaapvaal craton seismic tomography (dVs%) profile (28.62°N; 10°E - 45°W) of the TX2011 model (from http: //ds.iris.edu/dms/products/emc/horizontalSlice.html; access Jul. 2019) obtained to show the position of Olie-2 (= black vertical dashed line and indicated by arrow) in the Loxtondal Kaapvaal type lamproites cluster. Olie-2 is located in at high speed (below ~100 km up to ~180 km deep) to semi-high speed (below ~180 km up to ~280 km deep) -the high-speed zone can be attributed, for example, to the presence of diamonds by Garber et al. (2018).

Locally, Loxtondal cluster, in the geology is typified by Karoo aged sediments with dolerite sills (common). Lamproites/kimberlites in this area are generally sub-cropping and Cretaceous in age (Wit et al., 2016). Many kaapvaal-type lamproite in this area are closely associated with dolerite emplacement structures including faults and dykes and can often show slight positive topography as a result of resistive calcrete caps associated with the kaapvaal-type lamproite. Although unlikely, the presence of older (pre- to syn-Karoo age) kaapvaal-type lamproite cannot be discounted (partly as read from unpublished comments K.S. Viljoen in 2015). The Loxtondal kaapvaal-type lamproite were discovered in 1965 and they consist of a small (approximately 1 ha) pipe and eight dykes located on the farms Loxtondal, Klein Leeuwkuil and Una (Field et al., 2008).

3. Results and discussion

Olie-2

In this "noble area" (Loxtondal cluster) the focused to investigate the occurrence of diamond-bearing "kimberlites"; to start is seeking position of important faults that could facilitate "kimberlites" intrusions. Once located the most probable master faults in the area, using Landsat satellite image we identified two circular anomaly positioned above one of the "master fault" to which they are referred to as Olie-1 (~540 m in diameter) and Olie-2 (~1100 m in diameter) (Fig. 3 and 4). The circular pipe anomaly intrude basaltoids rocks (Karoo dolerite) (Olie-1) and Karoo sediments (limestone) (Olie-2).

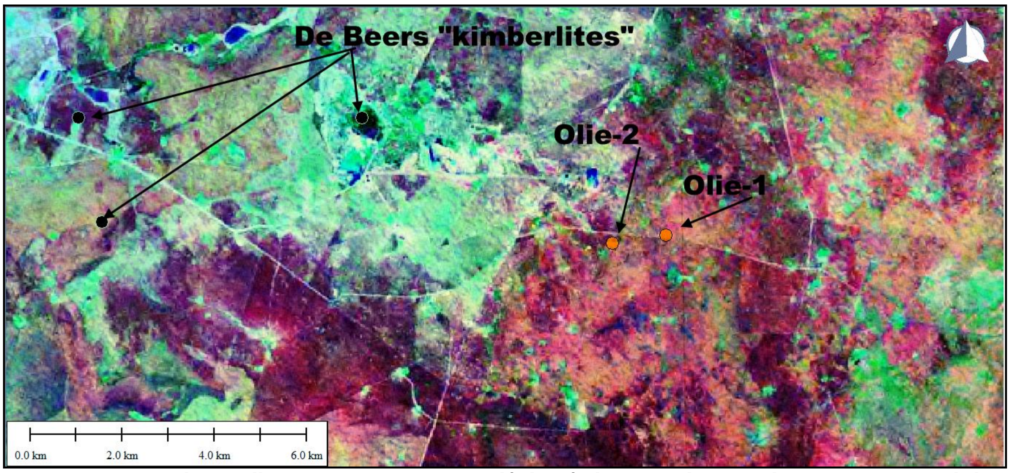

Fig. 3. Presser (2015) using Landsat satellite image (4/5, 1990) oneself identified two circular anomalous zones positioned above one of the "master fault" to which they are referred to as Olie-1 (~540 m in diameter) and Olie-2 (~1100 m in diameter) (orange balls). Note the presence of other "kimberlites" to the west, they discovered by De Beers.

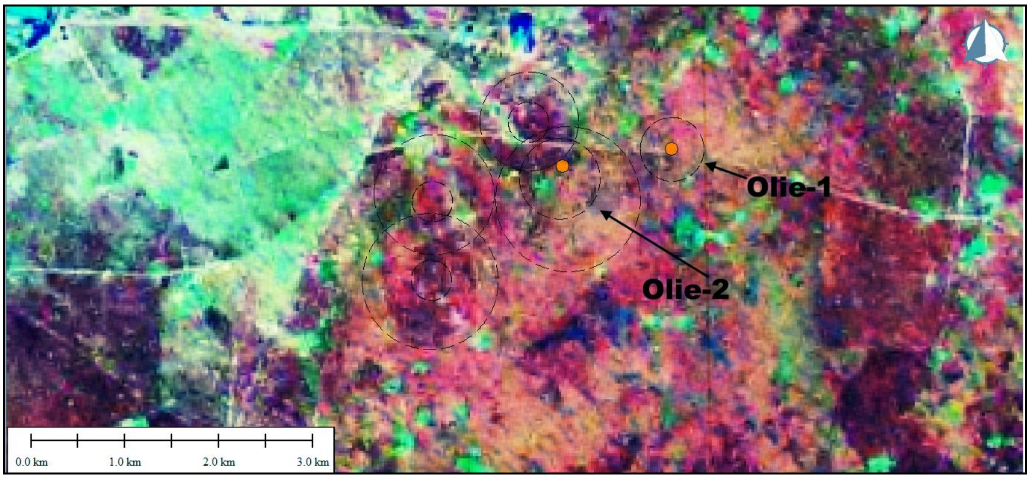

Fig. 4. Zoom of the previous figure on the circular anomalies (indicated by thin-circular lines) Olie-1 and Olie-2. Olie-2 would be part of an interlaced set of circular structures of outstanding size; probable others pipes are indicated on the west and southwest. Circular anomalies show a small circle outlined by a larger one. E-W wide stripes similar to those occupied by kaapvaal-type lamproites of eight dykes located on the farms Loxtondal, Klein Leeuwkuil and Una they are also visible along with Olie-2 although they don't stand out here. The points indicated in Olie-1 and Olie-2 correspond to the initial sampling sites whose content in indicator minerals and diamonds are commented on in the text.

3.1. Indicator Minerals (IM)

In previous work, Cole (2014) coment:
"Regional aeromagnetic and ASTER data were used to identify possible targets for kimberlite exploration in the prospecting area. A few areas for further follow-up work were identified based on their magnetic signatures, subtle changes in elevation and visual identification of circular features on the ATSER data. Further analysis of the ASTER data to identify spectra of indicator minerals yielded promising results, but field follow up work and detailed geochemical sampling is necessary before the targets can be confirmed or discarded as kimberlite pipes". Later, in soil samples (Horizon A) Visser (2014) found in the área IM: purple garnets, ilmenites, spinel and olivine. This was followed by the work of Presser (2015) that having identified the two targets of potential pipes later (also in 2014), those recommend sampling from two different points (within these anomalies); soil samples (~A/B Horizon), where they positioned themselves in at the coordinates:

Olie-1: -28.515228° and 24.957290°
Olie-2: -28.516652° and 24.945416°

So, we collect as 100 Kg of soil for Olie-1 and100 Kg of soil for Olie-2.

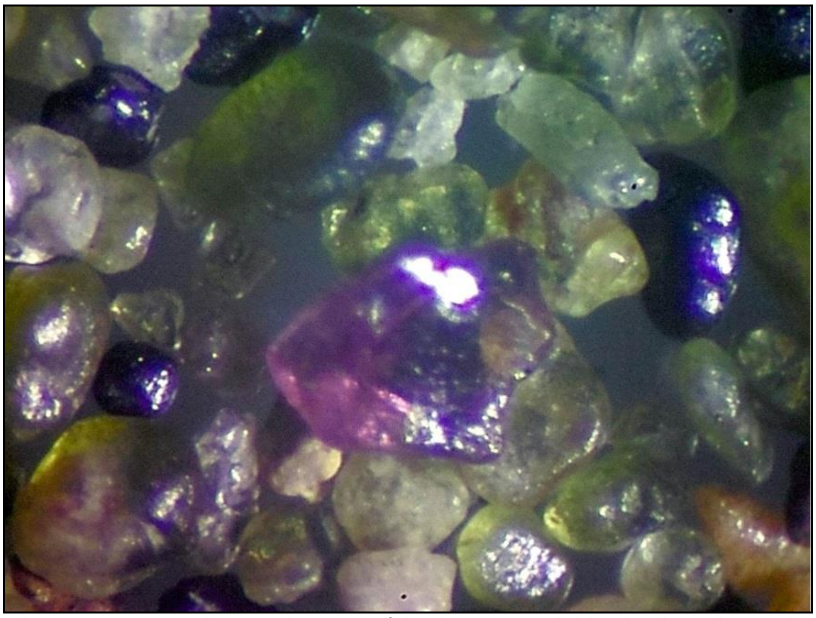

Fig. 5. Olie-2 IMs. A violet garnet (G-10) is shown in the center of the photo surrounded by abundant olivine (shades of green to yellow-green) and opaques (chromite and ilmenite). The IM current size are smaller than 0.5 mm.

A visual inspection (binocular loupe) of the concentrate of IMs (made by SGS laboratory - Johannesburg) of Olie-1 and Olie-2, when examined at high magnification loupe (10 to 80X) could see that are composed of: olivine, chromites, ilmenites, garnets, rutile, ilmeno-rutile, sapphire, tourmaline, as well as zircon, diamonds and rare fragments of emerald green Cr-diopside (Fig. 5). Since Olie-1 is in high concentration of rock fragments (altered diabase), whereas sporadic in Olie-2. Most of the IMs are smaller than 0.5 mm. (Fig.-5). Among Olie-1 and Olie-2 are clear differences between the bulk of IMs (Olie-2>Olie-1). The jobs mostly focused on Olie-2. The work of Visser (2014) and Presser (2015) contributed to raising the interest of some diamond geology groups that took new samples already individual at some points or following a mesh in an area of 400X400 m above the initial area of the recognition of Olie-2. Task that provided electron microprobe analysis of hundreds of chromites and garnets.

Olivine

Olivine occurs with rounded edges crystals of different sizes (0.1-0.5 mm) and less frequently as angular crystals (small crystals)(Fig. 5); and the concentration of this mineral is high and exceeds by far to the others IMs. No electron microprobe analysis of this mineral is available.

Chromites

Chromite crystals were seen in two extreme sizes; those between 0.2 to 0.5 mm. (interpreted as "***macro-crystals"***) and those are less than 0.2 mm. (groundmass-crystals). Macro-crystals are usually crystalline with distorted to elongate forms (as common in kimberlites with large amounts diamonds). Some macro-crystals are characteristically cherry-brown to depp-brown ("picro-chromites"). Fig. 6, based on the data analyzed by the aforementioned some diamond geology groups, show that they are chromites between 40% to 65% of Cr_2O_3. Yet, the chromites present tenor of TiO_2 <0.5 to 3.1% and MgO ~5-12%.

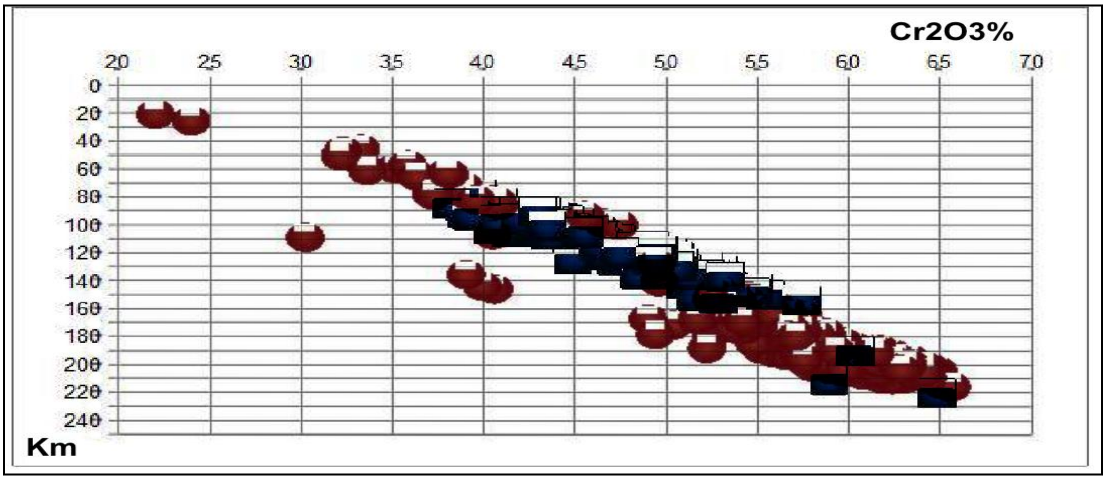

Fig. 6. Pressure Diagram (expressed in km of depth) *Vs* Cr2O3 (%) of the chromites analyzed in Olie-2 (black-white-blue squares) on chromites of other pipes of the same Loxtondal cluster (brown-white balls). The largest number of Olie-2 chromites are between 35 and 57% Cr2O2 (P =70 to 160 km deep). As will be seen later, this type of representation will allow more accurately the separation of chromites formed in diamond facies, from those formed in graphite facies. The pressure calculation is given according to the formula (empirical) Kb= Cr# X Cr2O3 (Presser, 1998). Olie-2 chromites N: ~250

Garnets

Garnets concentration is marked and occur frequently as angular to sharp edges smoothed small grains (0.2-0.4mm); displaying finely frosted (subkelyphitic surface surface texture) (both features indicative of no or limited transportation) with colors ranging from light red, dark red, light purple, medium purple, light pink purple, light pink, dark orange red and light orange (Fig. 5).

As is visible in the Fig. 7, also based on the data analyzed by the aforementioned some diamond geology groups, the garnets is most often those peridotitic G-10 (harzburgitic) and G-9 (lherzolitic); where the concentration of G-10 is obviously high.

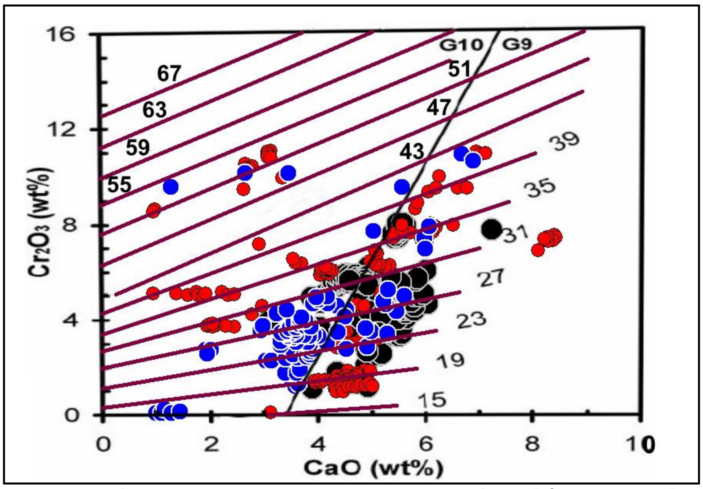

Fig. 7. Cr-in-garnet barometer (Grütter et al., 2006), = minimum pressure estimates derived from Cr-Ca relationships, in Olie-2 (blue balls) concentrate garnets on other pipes of the same Loxtondal cluster (red and black balls) concentrate garnets. In Olie-2 we can notice a high concentration of G-9 followed by the G-10; that reproduces pressures around 15 to 55 Kbr. It is customary to take as garnets of diamond facies those located on the line of 43 Kbr and below garnets of graphite facies. However, as will be seen later, this rule would not be of universal application and the pressure line that separates diamond garnets from those of the graphite facies garnets are rather drawn by the geothermal gradient. Olie-2 garnets N: ~250

Ilmenites

Ilmenite occurs as small grains (<0.3 mm) (mostly not broken) and as a groundmass grain type, with undisturbed surface to corroded-mostly (but without abrasion) and not broken. No electron microprobe analysis of this mineral is available.

Others IMs

Cr-diopside occurs as rare broken crystals. Rutile and ilmeno-rutile are common in small crystals (groundmass crystals). Other minerals also observed were brown tourmaline (frosting -crater facies tourmaline) and green sapphire. Zircon (frosting) is common but not abundant

(Presser, 2015). IM that is common to lamproites (*cf*, Fipke, 1994 and Presser, 2016).

Diamonds

In general, as we can read in Field et al. (2008), Loxton Mine (now also known as Don Diamonds), is noted that produced good quality diamonds, has been mined at a recovered grade of around 7 cpht. A dyke extension has also been mined and has grades of around 30 to 85 cpht.

In relation to the focus of this work, Presser (2015) to investigate the presence of diamonds in Olie-2, the volumes of IMs burned in the HFl. Residue from where they were clamped micro and small macro-diamond as octahedra to tetrahexahedroid, cube and irregular shapes, -mostly rounded (but without abrasion) crystals form. Diamonds show shades of colorless, pale yellow to pale brown, transparent to translucent (Fig. 8).

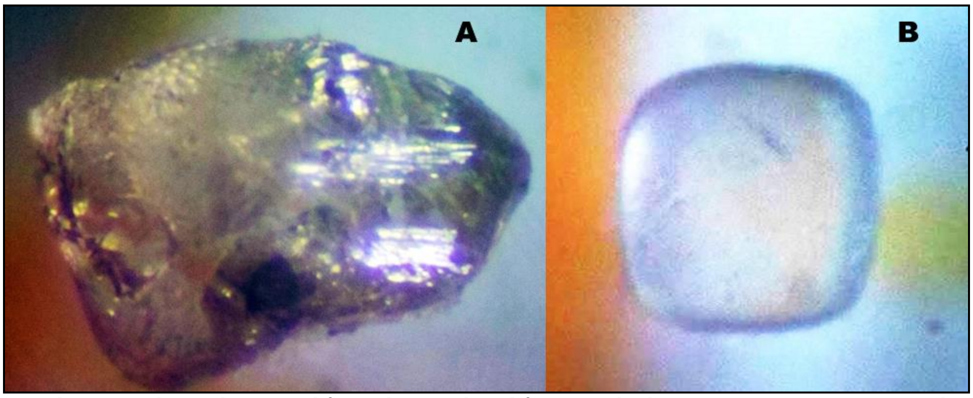

Fig. 8. Macro A) and micro B) diamonds extracted from Olie-2 (soil) HFl fusion residue by Presser (2015). A macro-crystal (0.6-0.7 mm) of slightly brown hue is shown; an irregular crystal with visible octahedron shapes on one of its edges, in the same crystal a small opaque inclusion is observed. The micro-crystal is a colorless cube somewhat rounded.

By way of confirmation, the Olies project manager sent another volume to the laboratories of the MSA Group (Pty) Ltd ("MSA") to undertake microdiamond analysis of one caustic fusion residue. MSA were processed the samples by caustic fusion by SGS South Africa (Pty) Ltd (SGS). Prior to submission MSA (2015) recovered 84 natural diamonds, weighed and described from the caustic fusion residue (Fig. 9).

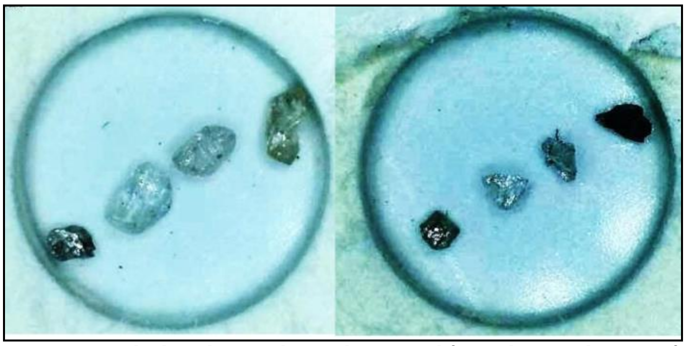

Fig. 9. MSA Group (Pty) Ltd selected micro-diamonds extracted from Olie-2 (soil) caustic fusion residue.

MSA highlighting that the stones larger than 300 micron were weighed individually on an ultra-micro analytical balance, and the weight converted to carat. Stones smaller than 300 micron were screened into different size fractions and weighed in combined groups per sieve class. The recovered diamonds by the MSA (2015) found that the collectively weighed 0.0779558 carats from the residue. 95% of all the diamonds described were transparent stones with 93% white/colourless, 5% brown and among other shades (Fig. 10). 79% of the stones found were broken crystals, consisting of 61% broken dodecahedrons and 26% fragments. 17% octahedrons were found (Fig. 11). 56% of the stones displayed frosted surface features and inclusions are present in 13% of the stones. The largest stone was a yellow transparent broken dodecahedron weighing 0.0109705 carats.

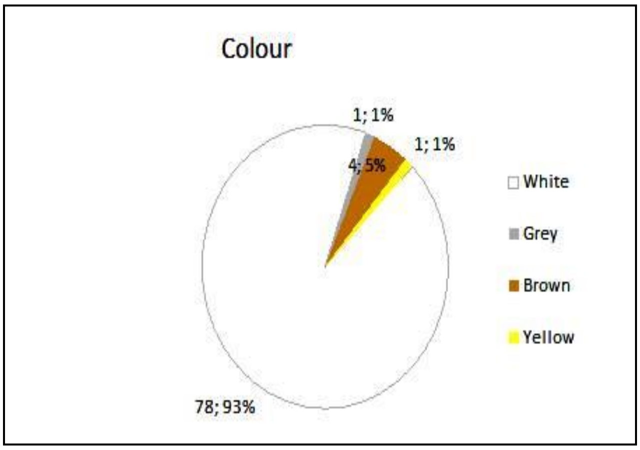

Fig. 10. The Colours of diamonds recovered by MSA (2015) from the Olie-2 IM sample caustic fusion residue.

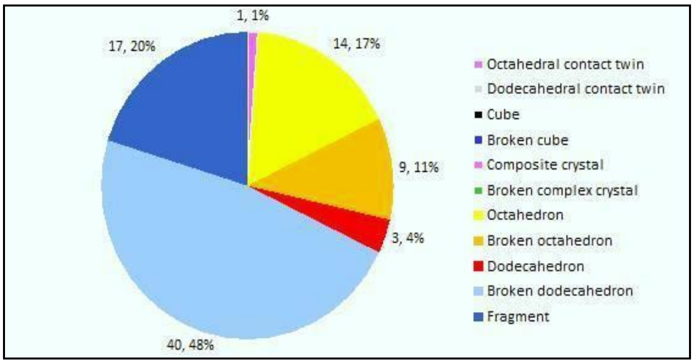

Fig. 11. The Crystal shapes and number of diamonds recovered by MSA (2015) from the Olie-2 IM caustic fusion residue.

4. Conclusion

4.1. Analysis and conclusion

In a cluster of lamproites/kimberlites with diamonds the indirect potential of the degree in diamonds, when the primary duct is not evaluated, could be suggested by the calculation of the surface heat flux (model); where the lowest values ("cold" geotherms), between the extreme values of 45, 40 and 35 mW/m2, are those that could host the greatest potent (*cf*, Simakov, 2018). Currently this task of estimating the surface heat flux (model) is done in the collection of xenocrysts and/or mantle xenoliths (both of them derived from disaggregated mantle-equilibrated rocks that pre-date the age of emplacement of the volcanic intrusión (Nowicki et al., 2007)) and/or diamond inclusion in/next to the pipes/etc. or it is estimated through the same data collection of several bodies of a cluster. This is customary to represent in graphs of pressure (P) *vs* temperature (T) i.e. paleogeotherm calculation through thermobarometry; as can easily be seen, for example, in Ashchepkov (2011) Ashchepkov et al. (2001, 2012, 2015, 2016a and b, 2017); Shchukina et al. (2017) as well as in the book collection of the Proceedings of International Kimberlite Conferences (1thIKC to 11thIKC). However, mismatches can occur in the inaccuracies of the calculation methods of P and T (mostly); see for example Copylova & Caro (2004); Grütter & Tuer (2009); Ashchepkov (2011); Ashchepkov et al. (2016a); Kobussen et al. (2018); Smith et al. (2018); Pearson et al. (2018); Bulanova et al. (2018); among others. Seismology can provide us with a present-day picture of the lithospheric thickness (Pearson et al., 2018); but at the same time a comparative study of the different deep root cratons shows that they would have remained, as a whole, properly unperturbed. Mismatches that can occur in the inaccuracies of the calculation methods of P and T; they would be minimized when the P data is combined with the seismic Vs 1D-Depth Profile as the path indicated by Garber et al. (2018) and is practiced in Presser (2019b) and Presser & Kumar (2019). Fig. 12 shows the winding of seismic Vs 1D-Depth Profile (of the coordinates of Olie-2; next to the Kimberley pipe coordinates) on a seismic tomography profile of the TX2011 Model (% dVs x-section) (line that cuts to Olie-2) and Fig.-13 agreeing the same information on which the P data (expressed in km) of garnet and chromite crystals of Olie-2 (data of Fig. 6 and 7); data that have been released next to the garnets data from other lamproites in the Loxtondal field (Fig. 7). Olie-2 is positioned on a surface heat flux (model) intermediate field between 40 mW/m2 and 35 mW/m2, apparently 37.5 mW/m2; information that suggests the diamond's stability field, for that environment, is below 120 km deep and around 280 km deep (=chromites with ~50 to ~66% of Cr2O3 see Fig.-6 and garnets with ~4 to ~11% of Cr2O3, see Fig. 7). This information is believed to reproduce with greater fidelity crystals that would form in the facies of the diamond and those that would form in the facies of graphite. On the other hand, this type of seismic information with the information given in Fig. 13 allows us to intuit that between 110 and 150 km there would be relatively depleted peridotites (lherzolites and harzburgites). And below until the LAB line a horizon of peridotites (lherzolites ± harzburgites) somewhat less depleted. The seismic Vs 1D-Depth profile for Olie-2 place also suggest, taking into account the comments in Garber et al. (2018), the greatest abundance of diamonds would be between 200 km and 280 km deep. Thus the P data agreed to the seismic information (Vs 1D and seismic tomography) suggest that Olie-2 is a diamond-bearing lamproite with a very interesting potential in diamond grade; potential that could approximate the degree of diamonds of the Kimberley "Kimberlite" pipe (200 cpht). However, this ideal diamond grade, according to Presser (2019b) and Presser & Kumar, (2019), would be based on the favorable structural conditions that prevail in the crystalline basement; task that was not included in this work. These comments allow us to conclude that Olie-2 shows to be part of a set of potential (large) interlocking pipes/some of which would include dykes of the same rock (Fig.-4) and thereby injecting a gigantic diamond area that could eventually be mined. The initial analysis of its diamond content suggests fancy color and colorless stones of gem quality (Fig.-10) which, if maintained in the same way in larger crystals, would transform into a very attractive diamond deposit.

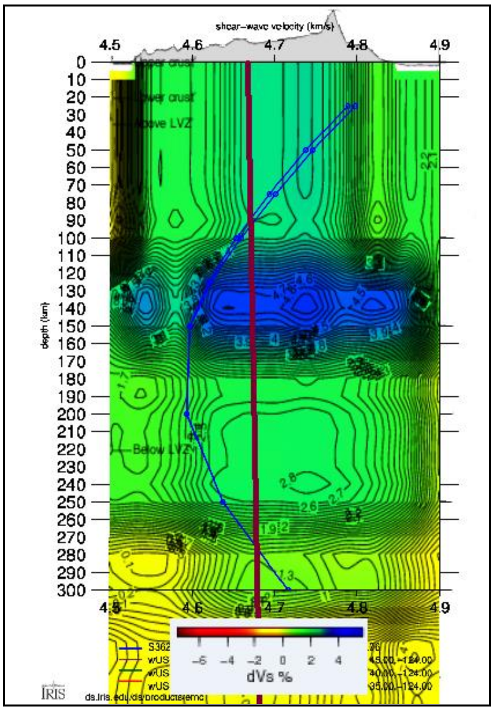

Fig. 12. Seismic section Vs 1D (blue line) for Olie-2 pipe anomaly site (= purple vertical line); in an adaptation of the work of Garber et al. (2018) the seismic section obtained from the model S363ANI + M of Moulik & Ekstrom, 2014 (from -http: //ds.iris.edu/dms/products/emc/horizontalSlice.html; =Iris, access Jul. 2019); positioned on a seismic tomography (dVs%) profile of the TX2011 model (obtained also from Iris) =zoom of Fig.-2. The seismic section Vs 1D that corresponds to the Olie-2 site more the Kimberley pipe site, that denote very minimal differences; seismic section which allows to intuit the horizons with greater and lesser concentration of diamonds (see comments in Fig. 2).

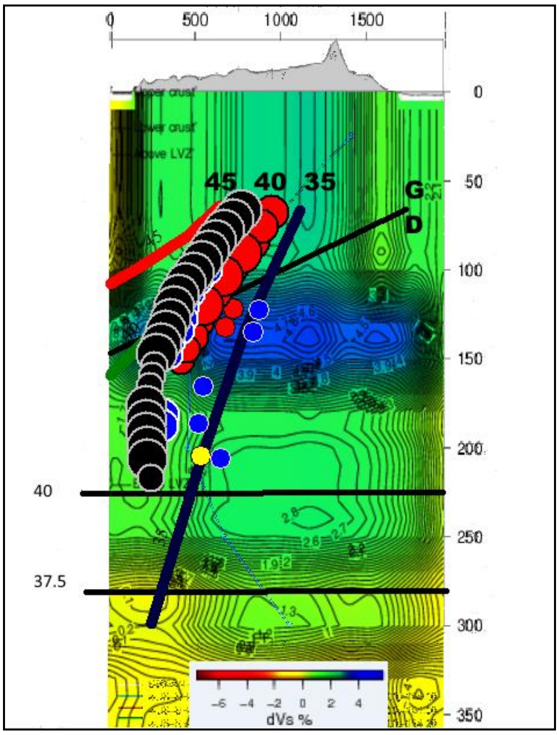

Fig. 13. This graphic, greater complexity to the previous figure, positioned the formation pressure information (appropriate to Km) of the chromites (black circles) and garnets (G-10 as blue balls and G-9 as red balls) from Olie-2 (to the left of the 1D Vs line) that contrasts with the composition of the same minerals that occur as the inclusion of diamonds from the Kimberley pipe (circles to the right of the 1D Vs line). The Olie-2/Kimberley-pipe geothermal gradients we can see that it corresponds to 37.5 mW/m2 (i.e., peridotitic cratonic (Archon) geothermal gradient). The figure allows the separation of chromites and garnets from diamond facies (DF) from the G/D line: 120 Km deep. So, chromites-DF 50-65% of Cr2O3; Garnets (G-10 and G-9) -DF with >4% Cr2O3. Supplement this information with Fig.-6 and 7. The lines in red, green and blue indicate the fields of surface geothermal gradient 45, 40 and 35 mW/m2. The LAB (lithosphere-asthenosphere boundary) for the 40 mW/m2 and 37.5 mW/m2 of surface geothermal gradient is also indicated by the black horizontal line. G = graphite and D = diamond. The size of circles is adapted to the highest concentration (major circles) to low concentration (minor to individual circles).

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