Diamond potential of the lithospheric mantle beneath the Limpopo Mobile Belt (southern Zimbabwe) based on the geochemistry of mantle garnets.

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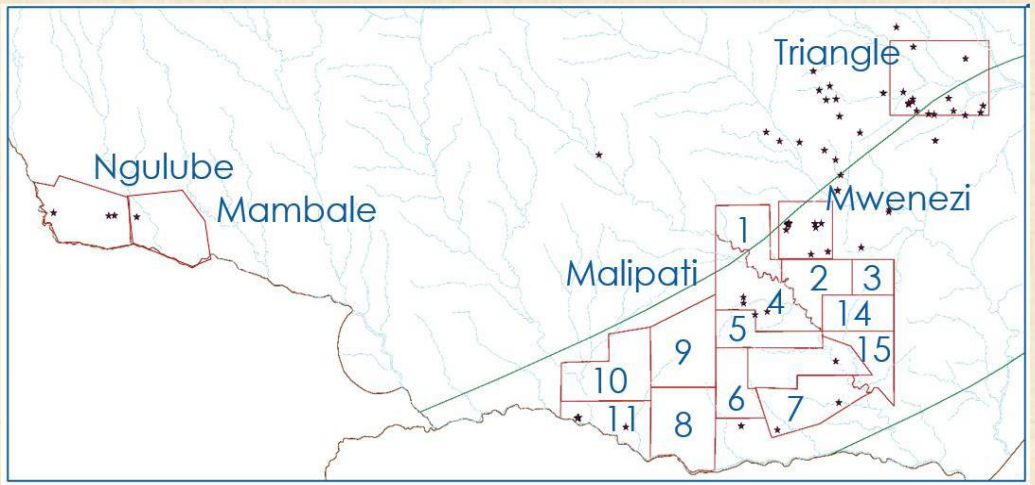
EXPLORATION WORKS

- Alrosa (Zimbabwe) company conducted an exploration program to search for new kimberlites on their licenses in the south of the country (Matabeleland South) during the period 2020 to 2024.
- In this province, ALROSA (ZIMBABWE) Ltd. has received 15 licenses, covering a total area of approximately 720,000 hectares. The licensed areas contain known mineralogical anomalies and more than 36 known kimberlites of varying degrees of exploration.
- The same time a re-evaluation of several previously discovered (JK-01, Triangle-11, 12) kimberlites was carried out.



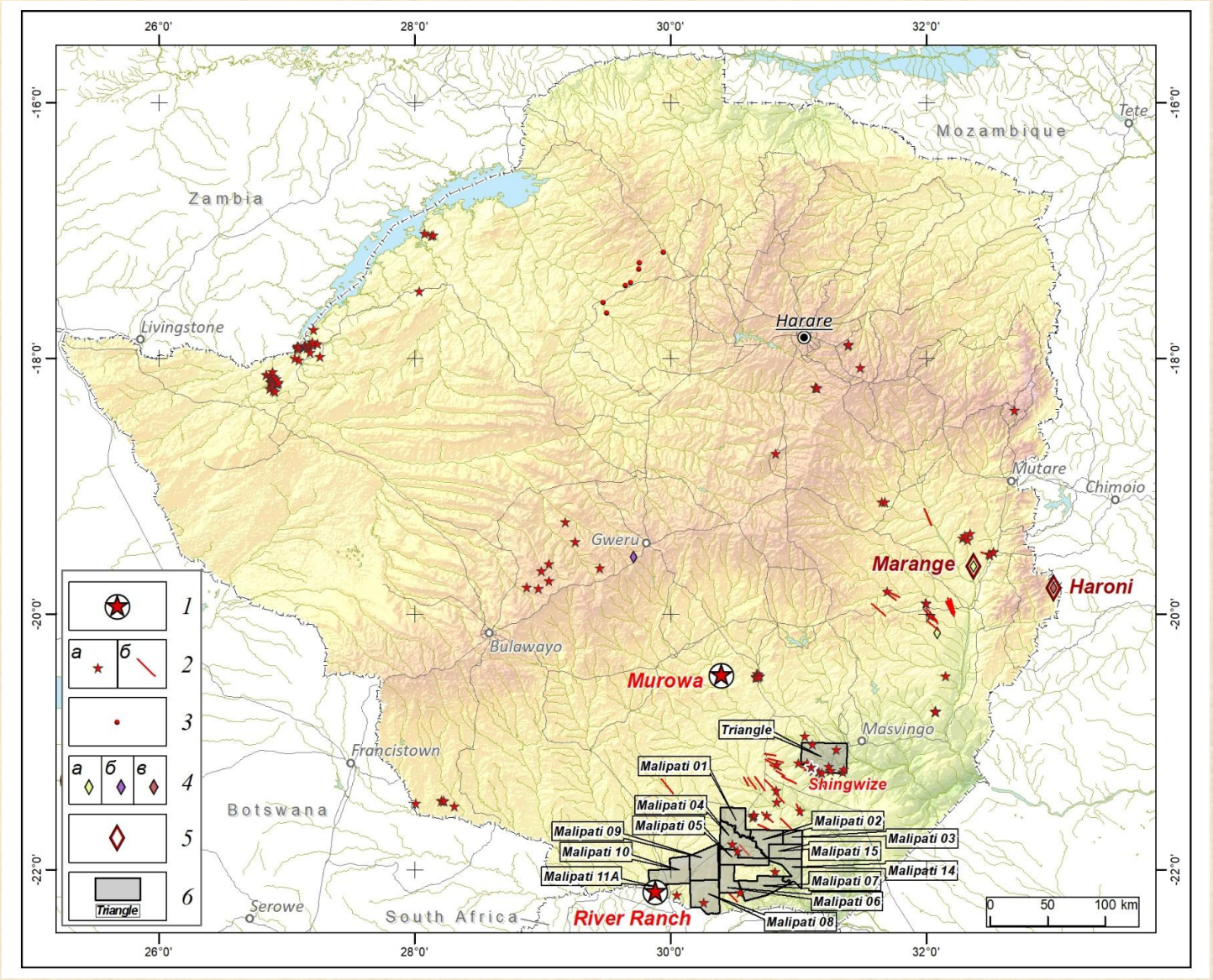
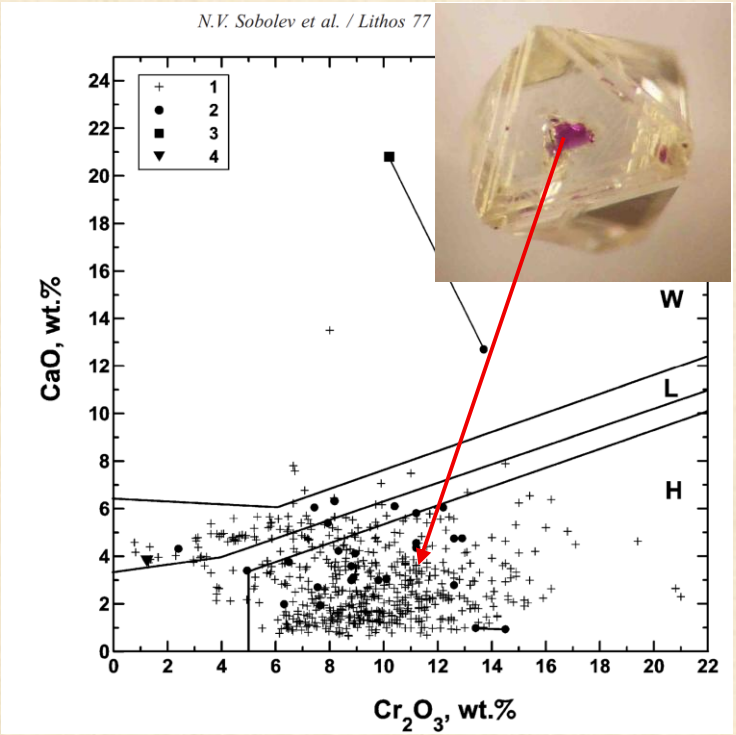


Fig. 1-2. The map of Zimbabwe with defined location of the prospecting licences for diamonds of Alrosa (Zimbabwe).

THE DIAMONDS GROWTH CONDITIONS

It is important to remember a necessary conditions for stable growth of diamonds in the lithospheric mantle. There are still many questions here, but in general it is known that:

- Most diamonds record formation along the 35-45 mW/m^2 geotherms and close to the diamond graphite boundary (4.5-7.5 GPa, 950-1350 C).
- Carbon source in the mantle (eclogitic and peridotitic diamonds) - carbon-bearing fluids or minerals, depending on oxygen fugacities.
- The close similarity diamond inclusions and minerals in diamondiferous xenoliths strongly suggests that diamonds were formed within such rocks long before the kimberlite eruption and are not phenocrysts in the erupting kimberlite.



- The mineralogical criteria for the diamond potential of kimberlites are based on the study of the composition of pyrope garnets included in Yakutian diamonds: they differ from the composition of ordinary pyropes from kimberlites in two respects: a higher chromium content and a lower calcium content.
- This criteria was developed by Academician Sobolev, who published it in 1971.

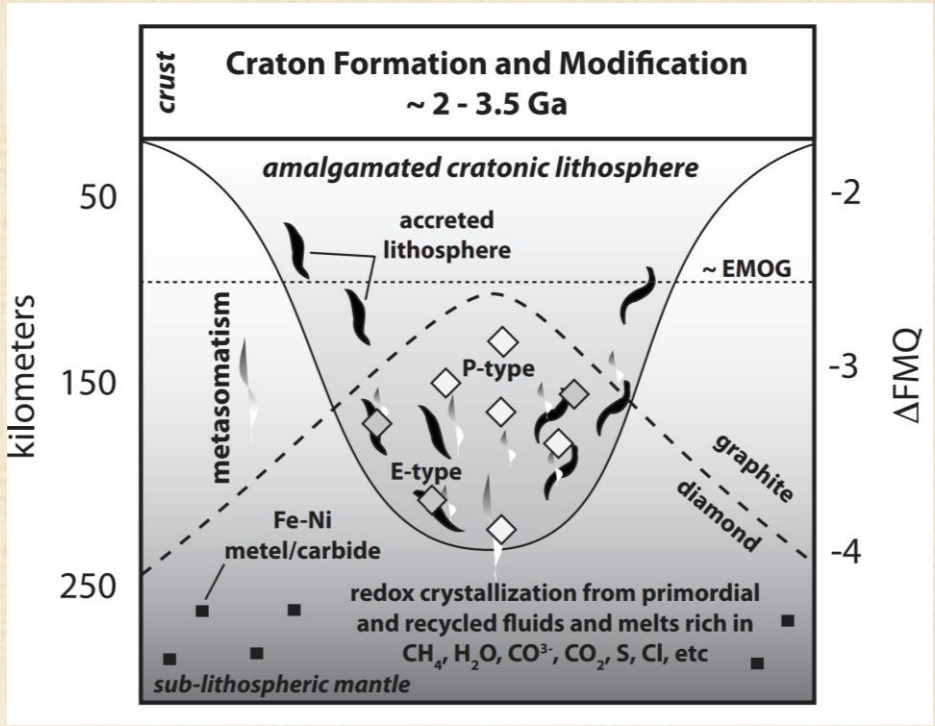


Fig. 3. Schematic diagrams illustrating possible mantle conditions (e.g., depth, oxygen fugacity) and geodynamic settings in which lithopsheric and sub-lithospheric diamonds and their mineral inclusions are formed. The figure after Shirey et al

Fig. 4. CaO vs. Cr_2O_3 in Cr-bearing pyropes from macrodiamonds of major Yakutian diamond mines (1) and from microdiamonds of the same mines (2). Solid boundaries for garnet parageneses are from Sobolev (1971, 1974). H—harzburgitic, L—lherzolitic, W—wehrlitic parageneses.

GEOLOGICAL POSITION

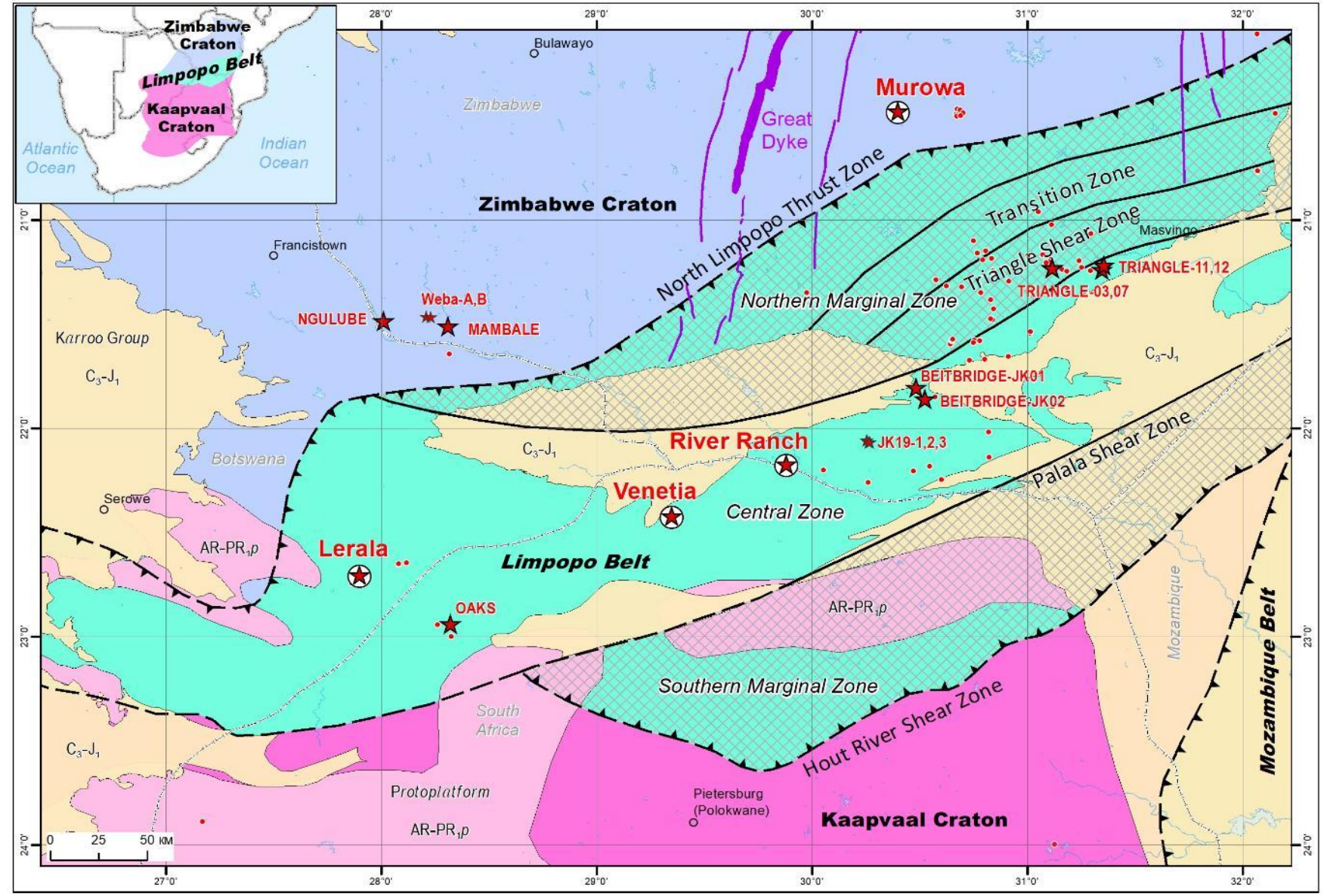
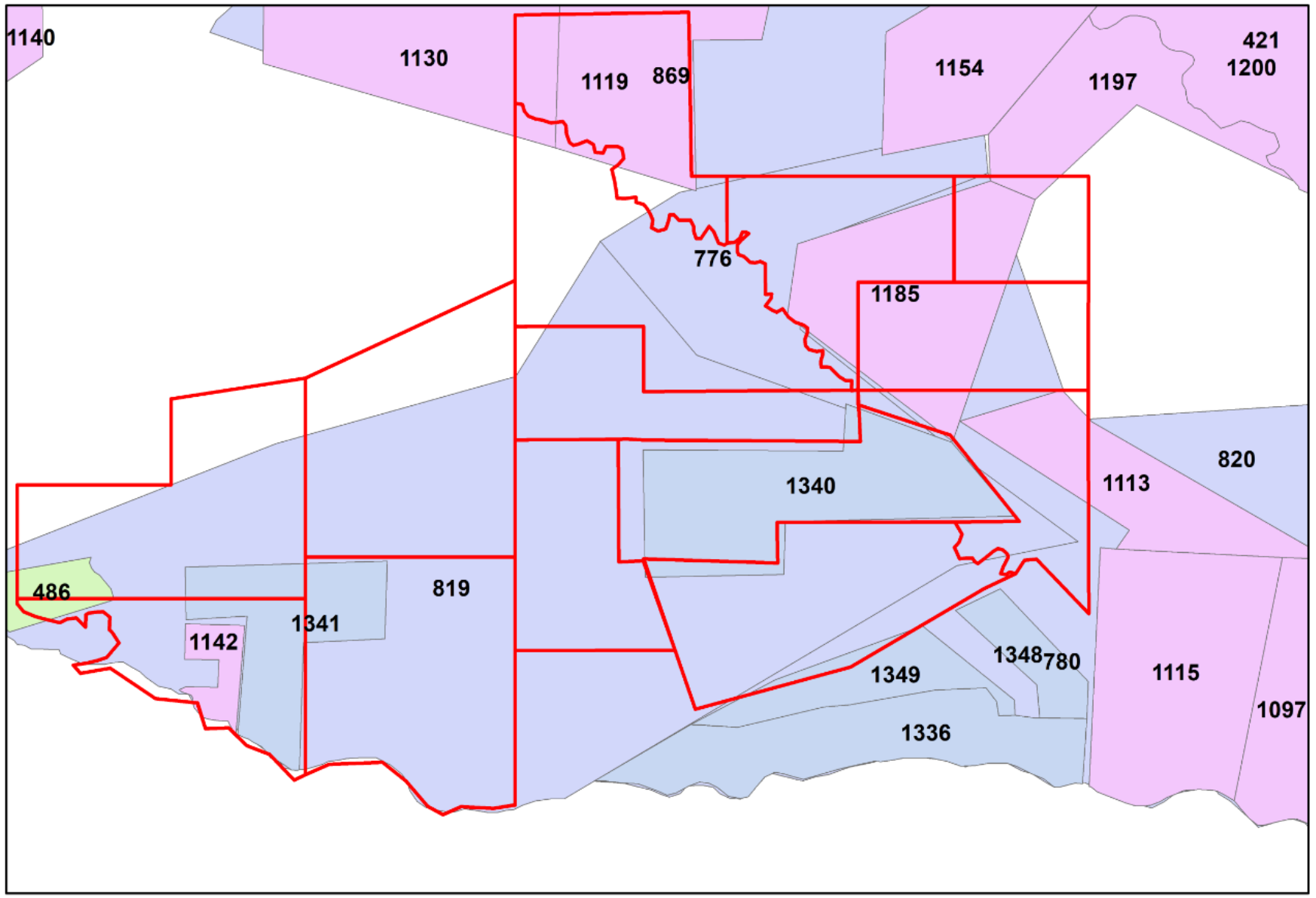


Fig. 5. Tectonic map of the Limpopo mobile belt, southern Zimbabwe (adapted from Blenkinsop and Kisters, 2005).

- The studied kimberlites are located within the Central Zone of the ancient (early Archean) Limpopo mobile belt, which separates the Kaapvaal and Zimbabwean cratons, and represents a complex structure composed of a tectonically displaced allochthon, which has no connection with the lithospheric mantle (De Wit and Hart, 1993).
- According to published data, the lithospheric mantle beneath this belt is completely analogous to that beneath the Kaapvaal craton, i.e., represented by a depleted, relatively cold lithosphere composed of low-temperature garnet peridotites (Kopylova et al., 1997).
- **In other words, from a tectonics point of view, this area and the conditions in the lithospheric mantle beneath it are favorable for the localization of diamond-bearing kimberlites.**

EXPLORATION WORK



- In southern Zimbabwe, two major companies (Rio Tinto Zimbabwe and De Beers (Kimberlitic Searches Limited)) were conducting diamond exploration.
- The location of the exploration license boundaries relative to the boundaries of the ALROSA (Zimbabwe) special grants is shown in the figure.
- ALROSA (Zim) was carried the exploration program out using the traditional mineralogical method.

Fig. 6. Position of license areas (EPO) of companies that previously carried out exploration work relative to the license areas of ALROSA (Zimbabwe).

MINERALOGICAL LAB

Fig. 7-10. During the loam sampling program, the company was using a full cycle of loam samples processing based on its own facilities (field camp and BYO office).

EXPLORATION WORK

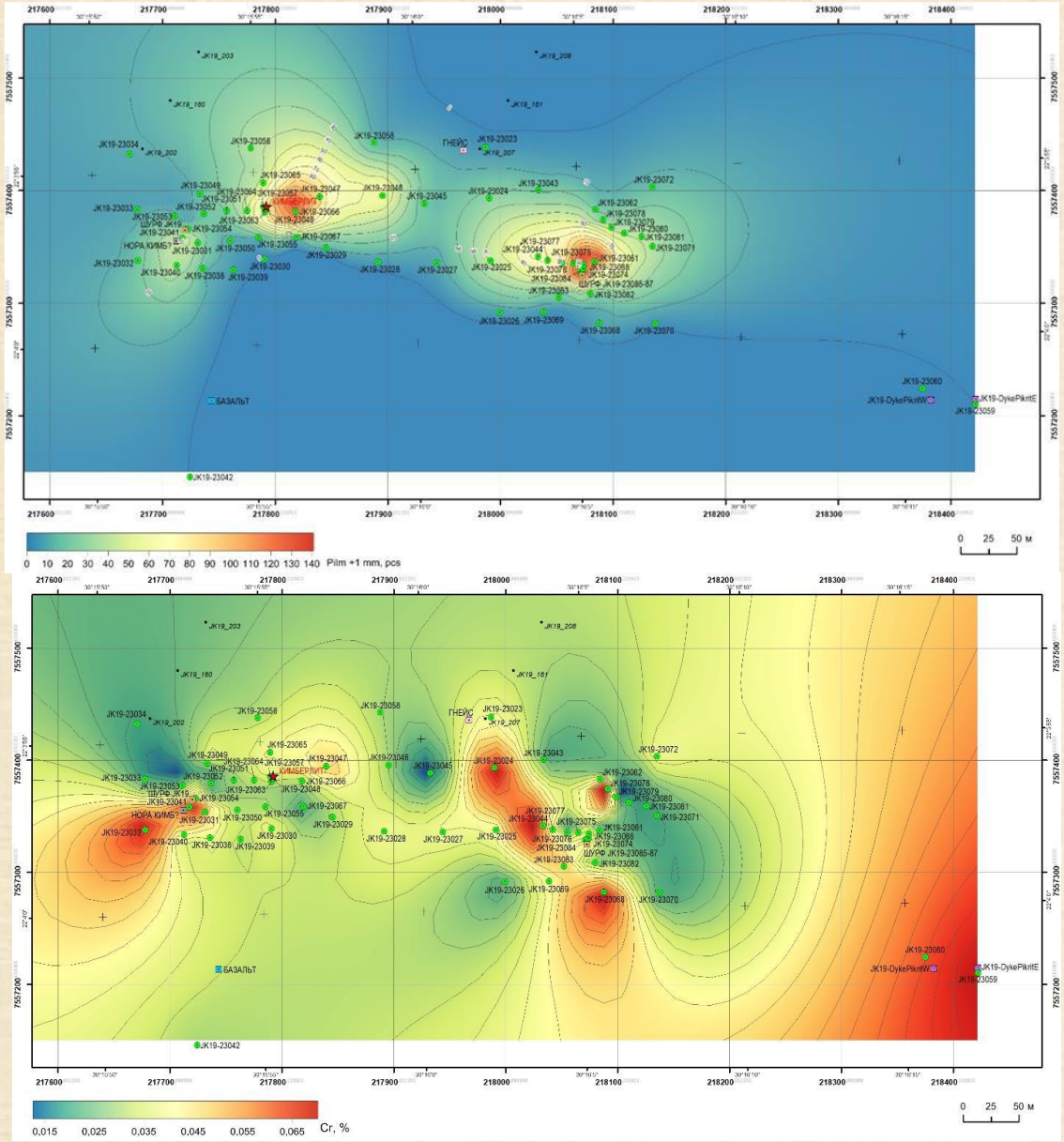


Fig. 11. Microscopic photos of the indicator minerals of kimberlites (JS19 sampling site).

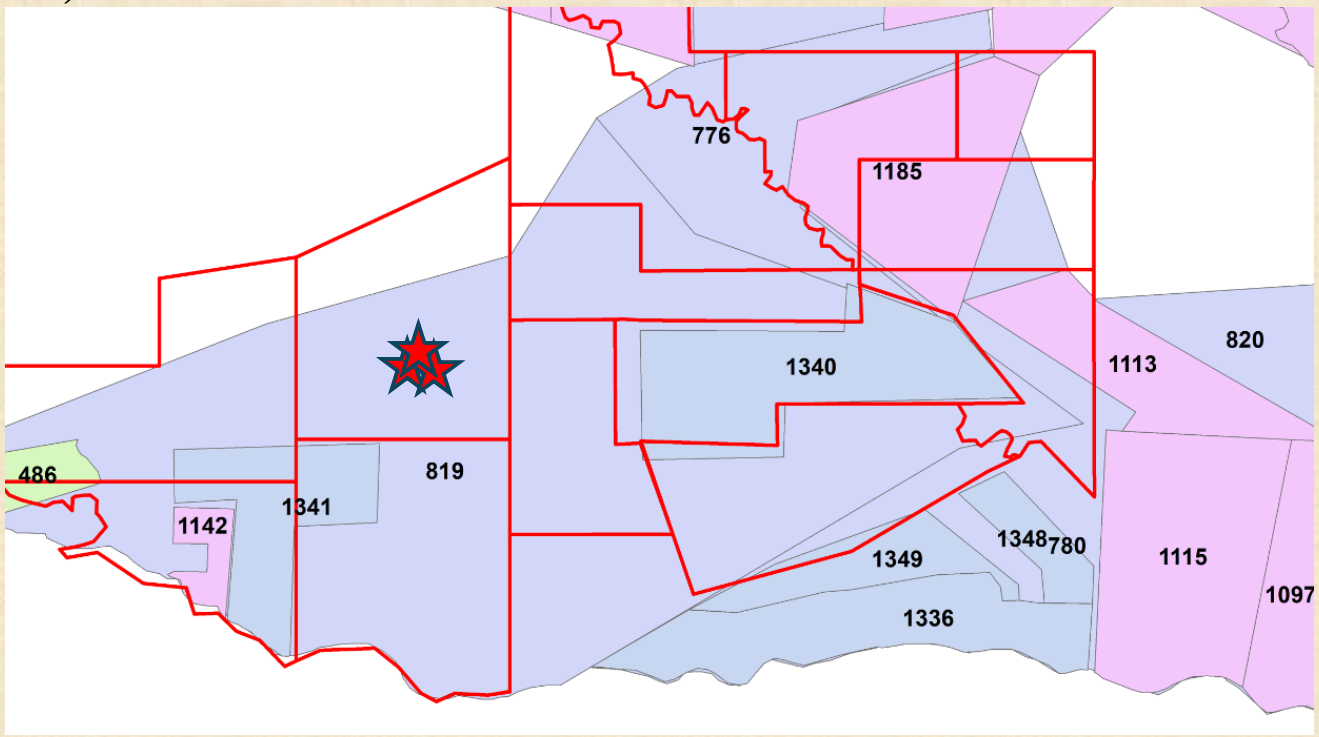


Fig. 12-13. Concentration contours of +1 mm class picroilmenites and chrome spinels in the south-east corner of area JS19 (kimberlite is shown by the stars).

Fig.14. A pit that exposed a kimberlite dike JK-19/1.

Fig.15. A trench that exposed a kimberlite dike JK-19/2.

Fig. 16. The pit that exposed a kimberlite and fragments of kimberlite rocks (area JS-19 of the Malipati license area).

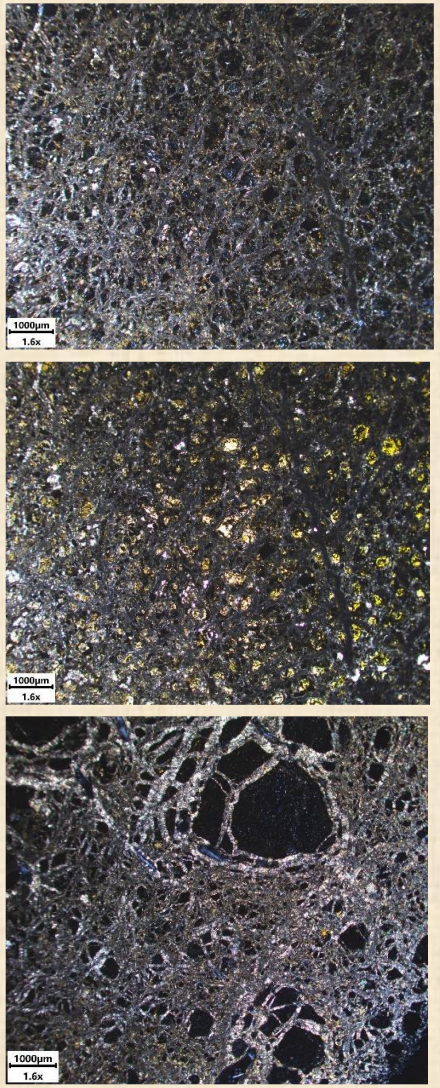
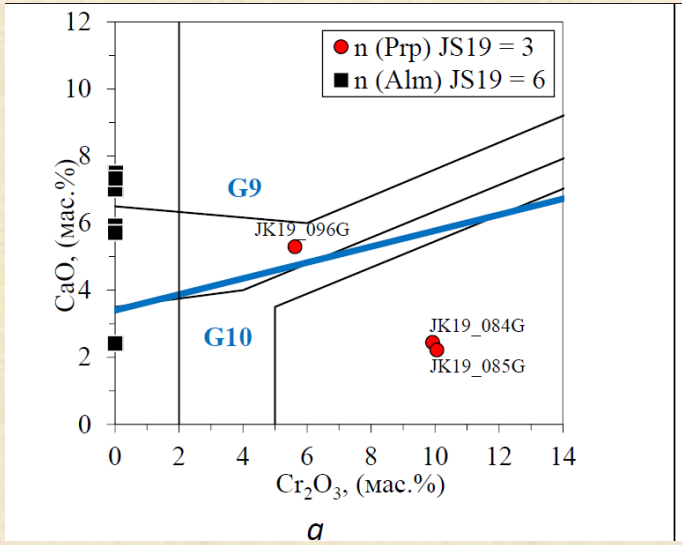


Fig. 17. Polished porphyry kimberlite sample from the JS-19 site.

JK-19 KIMBERLITE MINERALS COMPOSITION



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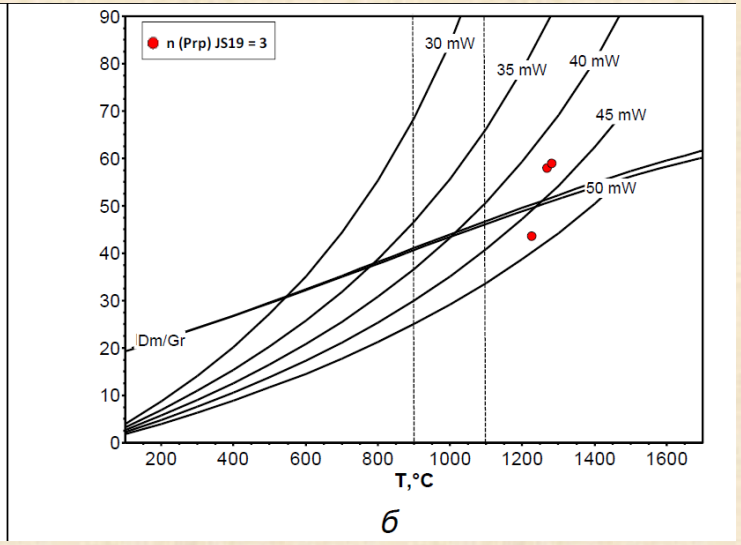

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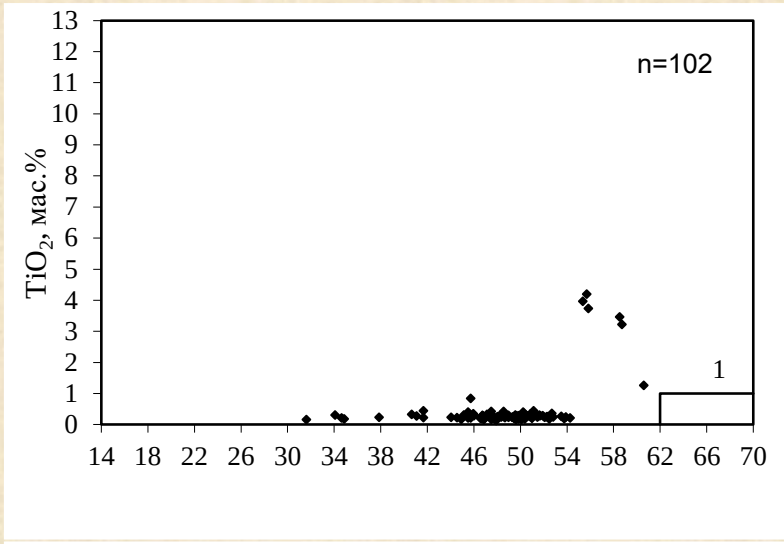
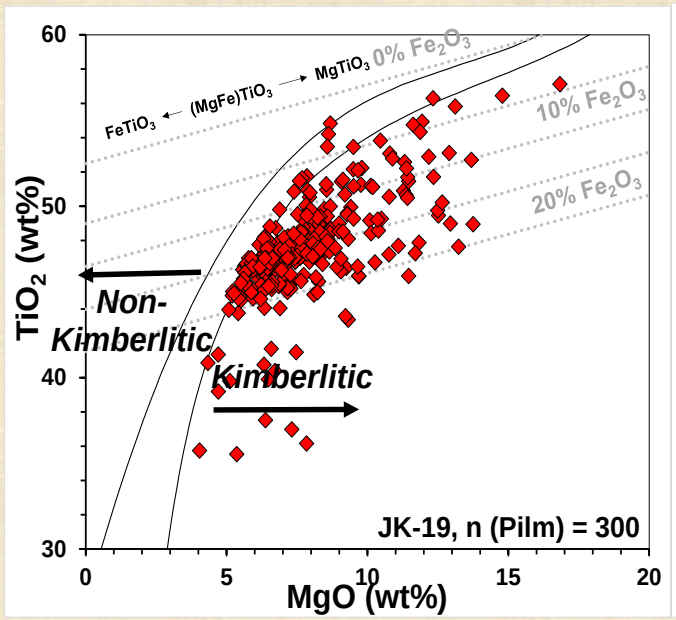
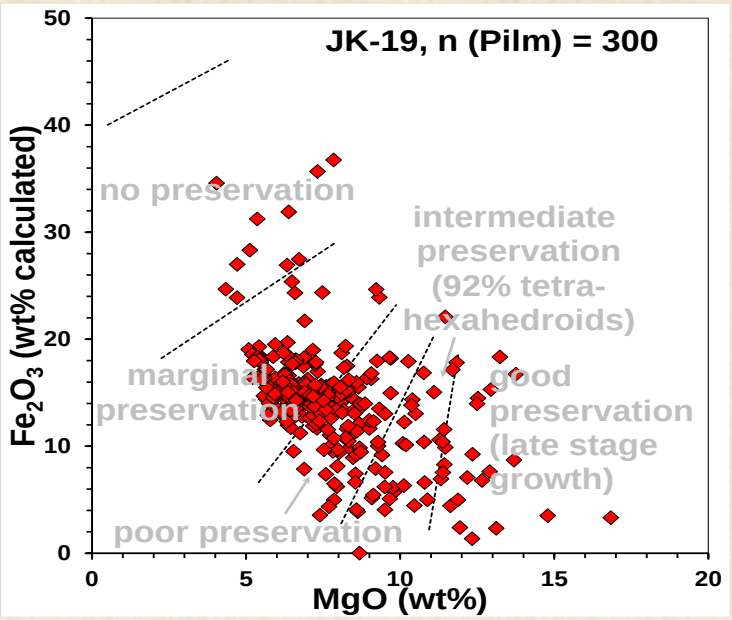






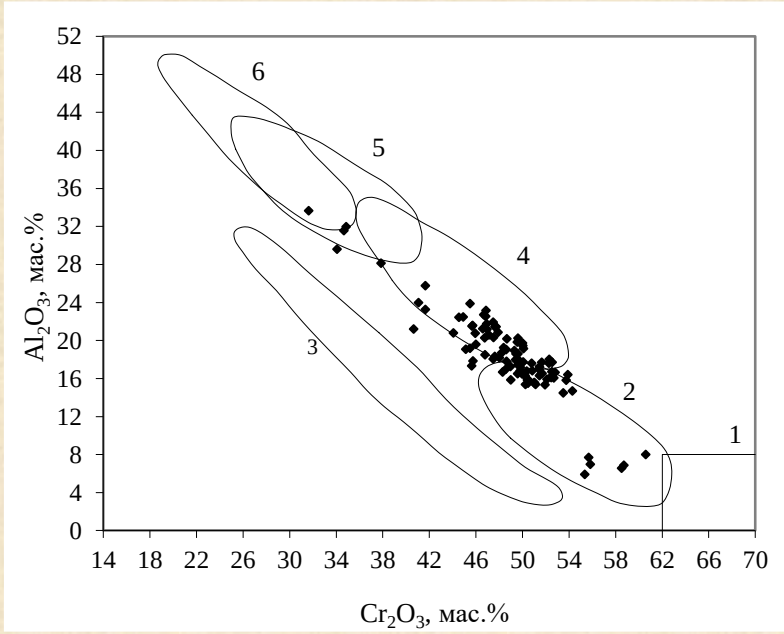


Fig. 18-20. The composition of pyropes, picroilmenites and Cr-Spinels from JS19 sampling site. In the diagrams: a - N.V. Sobolev [Sobolev, 1974] and J. Gurney [Gurney, 1984, 1989; Gurney et al., 1993], b - results of calculation of P-T parameters in the PTQuick program.

BULK SAMPLING OF THE KIMBERLITES

Fig. 21. A trench on the JK-01 kimberlite sampling site (left) and the stockpile of the kimberlite bulk sample.

Kimberlite	Bulk sample, tons	Diamonds recovered	Weight, ct
JK-01	105.9	129	5.5
TR-11	68.8	0	0
TR-12	55.6	0	0

Fig. 22. Exploration plant at the Bubi camp and the department of the final diamond recovery.

JK-01 DIAMONDS CHARACTERISTICS

Characteristics	Size class, mm		
	-4,0+2,0	-2,0+1,0	Total
Quantity ,pcs	10	119	129
Weight, ct	1,64	3,86	5,50
Variations of the weight, Ct:			
- Min	0,09	0,01	
- Max	0,30	0,10	
Average wight of stones, Ct	0,16	0,03	0,04
Quantity of diamonds in one Ct	6,10	30,8	23,5
Share in % of the total quantity:			
- In pcs	7,8	92,2	100,0
- In Ct	29,8	70,2	100,0
Cost (preliminary), USD/ct:			
Prises from 02-15-01-2019 -July according to "Natural, rough diamonds" (Ministry of Finance of Russia)	46,44	30,74	35,42

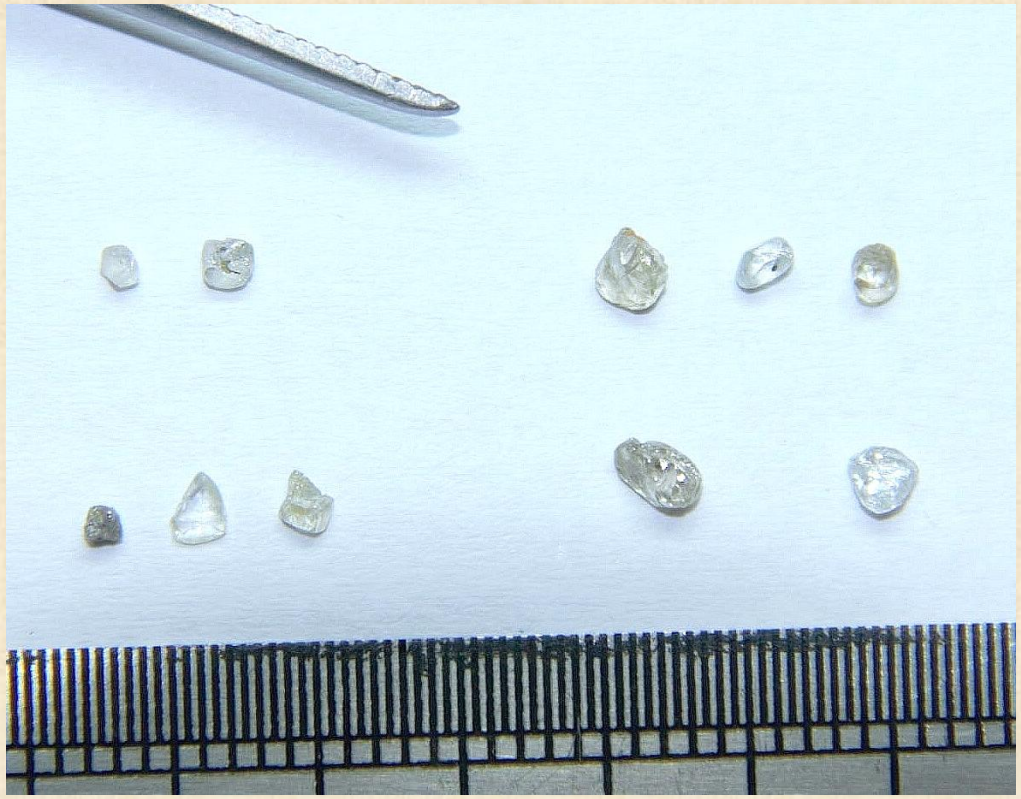


Fig. 23. Photo of the diamonds recovered from the JK-01 kimberlite.

- a predominance of diamonds without cracks, but with numerous inclusions, transparent, jewelry stones (of reduced quality) of a light color range.

Despite promising preliminary forecasts, all tested kimberlites showed negative ore potential.

FORECAST OF KIMBERLITES DIAMOND POTENTIAL

We have decided to look into the situation and understand the reasons for the failure of diamond-bearing forecasting methods in this particular case. During any diamond exploration works, there are several decision points at which exploration can be stopped if the forecast is negative.

1. **Early exploration stage.** At this stage, it is possible to understand the diamond potential of an as-yet-undiscovered or discovered kimberlite using mineralogical criteria for diamond potential.

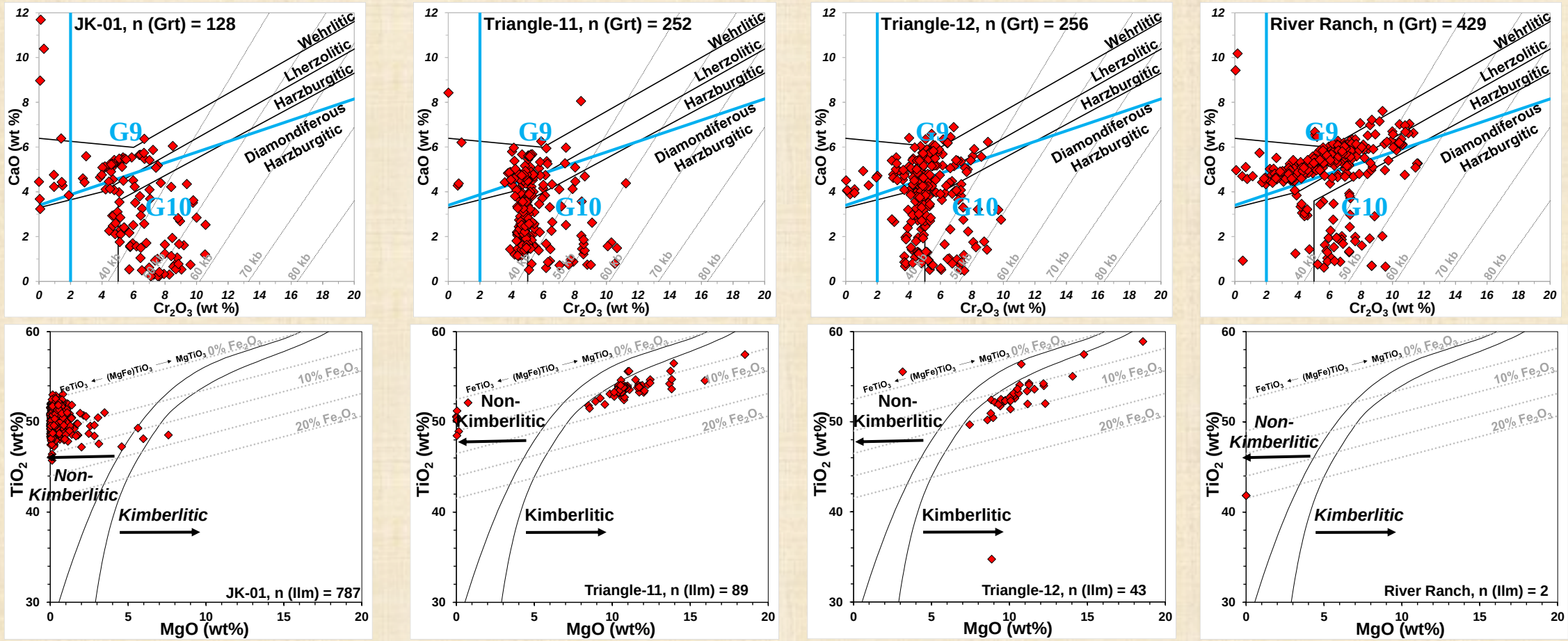


Fig. 24. Composition of the mantle garnets from kimberlites JK-01, Triangle 11 in 12 on the diagrams: N.V. Sobolev [Sobolev, 1974] and J. Gurney [Gurney, 1984, 1989; Gurney et al., 1993] (upper row); composition of the picroilmenites from kimberlites JK-01, Triangle 11 in 12 on the diagrams TiO_2-MgO of Wyatt [Wyatt B.A., 2004].

DIAMOND PRESERVATION FORECAST

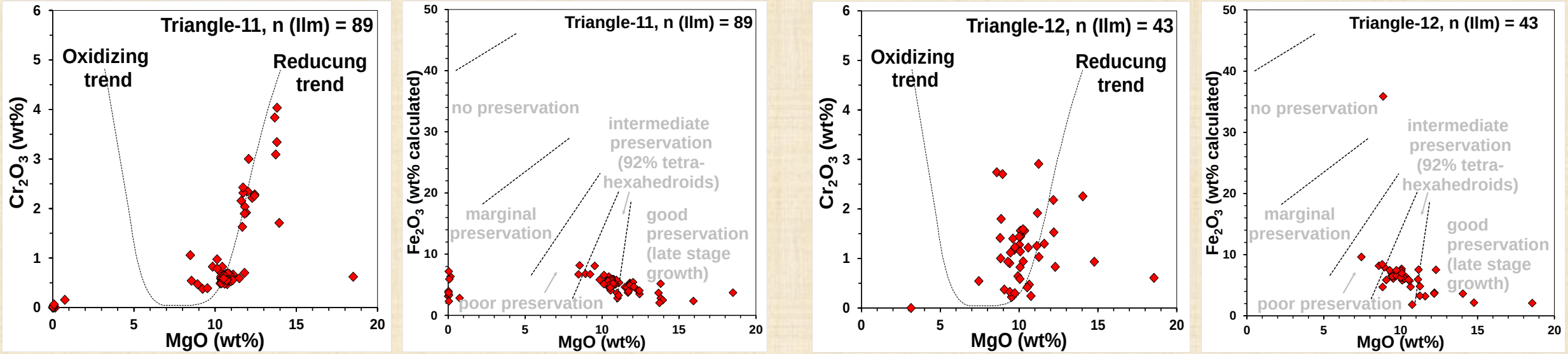


Fig. 25. Composition of picroilmenites on the diagrams of Haggerty [Haggerty S.E., 1975] and Nowicki et al [Nowicki et al, 2007].

By using a picroilmenite composition we can also predict a degree of diamonds preservation in the source kimberlites.

Based on the chemical analysis of kimberlite indicator minerals, the kimberlites of the Triangle cluster (11, 12) and the Beitbridge JK-01 kimberlite dike have the greatest potential among the studied kimberlites located within the Malipati licensed area cluster.

FORECAST OF KIMBERLITES DIAMOND POTENTIAL

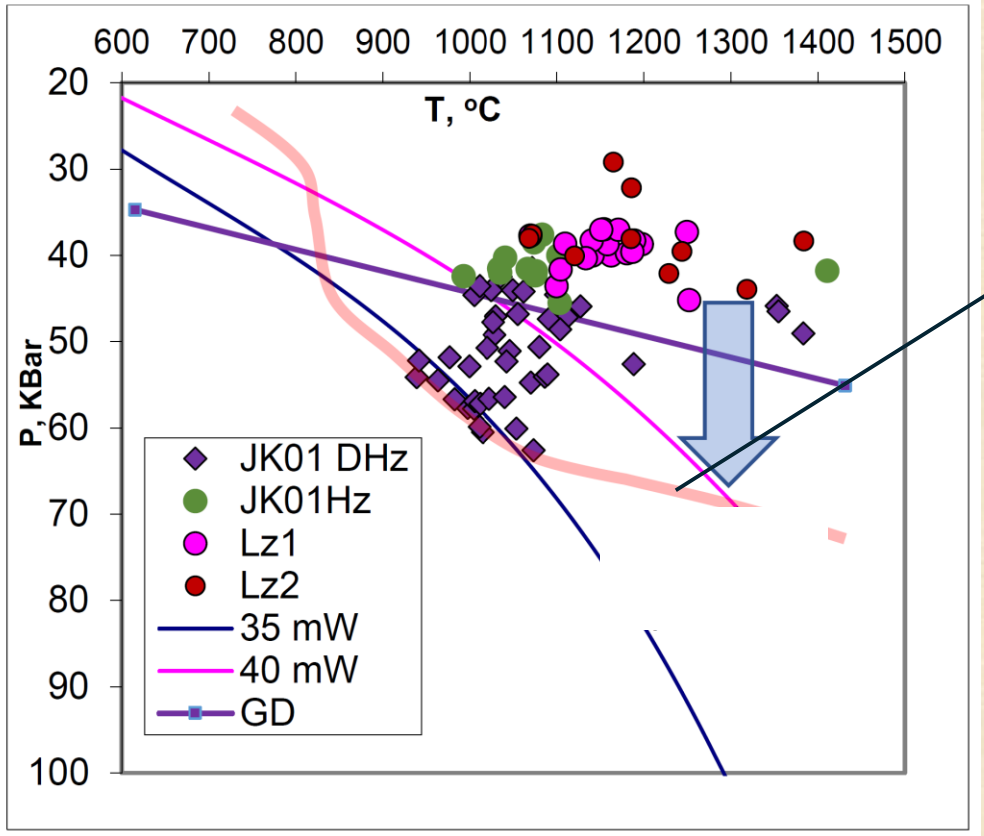


Fig. 4. The P-T parameters for HD pyropes were calculated using the Ni-in-garnet thermometer according to Griffin [Griffin et.al., 1989] and the barometer according to Ryan [Ryan et.al, 1996].

"Udachnaya" Kimberlite Geotherm

2. Next stage is kimberlite discovery stage. Kimberlite testing for microdiamonds. Decision-making based on a mathematical model for predicting diamond content based on the presence of microdiamonds in small kimberlite samples. This is a low-cost method compared to bulk sampling.

Among the Triangle cluster kimberlites, microdiamonds have been found in variable amounts in eight kimberlites (TRG-01; TRG-03; TRG-05; TRG-07; TRG-08; TRG-10; TRG-11; TRG-12).

3. Next stage is kimberlite bulk sampling. A method for assessing the diamond potential of a kimberlite body. This method is reliable but expensive.

For the most of the worldwide kimberlites the positive conclusions on the first two criteria would means a discovery of an almost guaranteed diamond productive kimberlite.

But in fact, we got almost barren kimberlites.

FORECAST OF KIMBERLITES DIAMOND POTENTIAL

To understand the failure of the mineralogical method for predicting diamond potential in this particular case, we performed EMPA and LA ICP MS analysis for rare and trace elements in mantle garnets from the studied kimberlites. The statistics of analysed minerals is provided on the screen.

Kimberlite	C2	E1	E2	MC	PR							Total Grt,
					HD1	HD2	L1	L2	L3	W	Total PR	
JK-01	4	1	3	3	34	36		1	45	1	117	128
JK-02					28		2	88	18		136	136
River Ranch	2	5		15	36	29	4	9	328	1	407	429
Triangle-11	1	2	1		157	24	1	9	57		248	252
Triangle-12	1	5	1		106	20	19	45	59		249	256
Triangle-7		1		9	36	26	1	144	88		295	305
Summary	8	14	5	27	397	135	27	296	595	2	1452	1506

Кимберлит	C2	E1	E2	MC	PR							Total Grt, to 100%
					HD1	HD2	L1	L2	L3	W	Итого PR	
JK-01	3,1%	0,8%	2,3%	2,3%	26,6%	28,1%		0,8%	35,2%	0,8%	91,4%	100,0%
JK-02					20,6%		1,5%	64,7%	13,2%		100,0%	100,0%
River Ranch	0,5%	1,2%		3,5%	8,4%	6,8%	0,9%	2,1%	76,5%	0,2%	94,9%	100,0%
Triangle-11	0,4%	0,8%	0,4%		62,3%	9,5%	0,4%	3,6%	22,6%		98,4%	100,0%
Triangle-12	0,4%	2,0%	0,4%		41,4%	7,8%	7,4%	17,6%	23,0%		97,3%	100,0%
Triangle-7		0,3%		3,0%	11,8%	8,5%	0,3%	47,2%	28,9%	0,0%	96,7%	100,0%

MINERAL INCLUSIONS IN DIAMONDS

- We saw that, according to the kimberlite mineral composition, the lithospheric mantle is characterised by the necessary conditions for diamond formation.
- We know also that the diamonds grow during the metasomatic process with the influx of fluids.
- How can we understand the reason the diamonds did not grow up for ?
- To understand the conditions in which diamonds grow, the simplest way is to study these minerals—the inclusions in these diamonds.
- The minerals encapsulated in the diamonds preserve the information on the mineralogy and geochemistry of the mantle environment at the time of diamond formation.

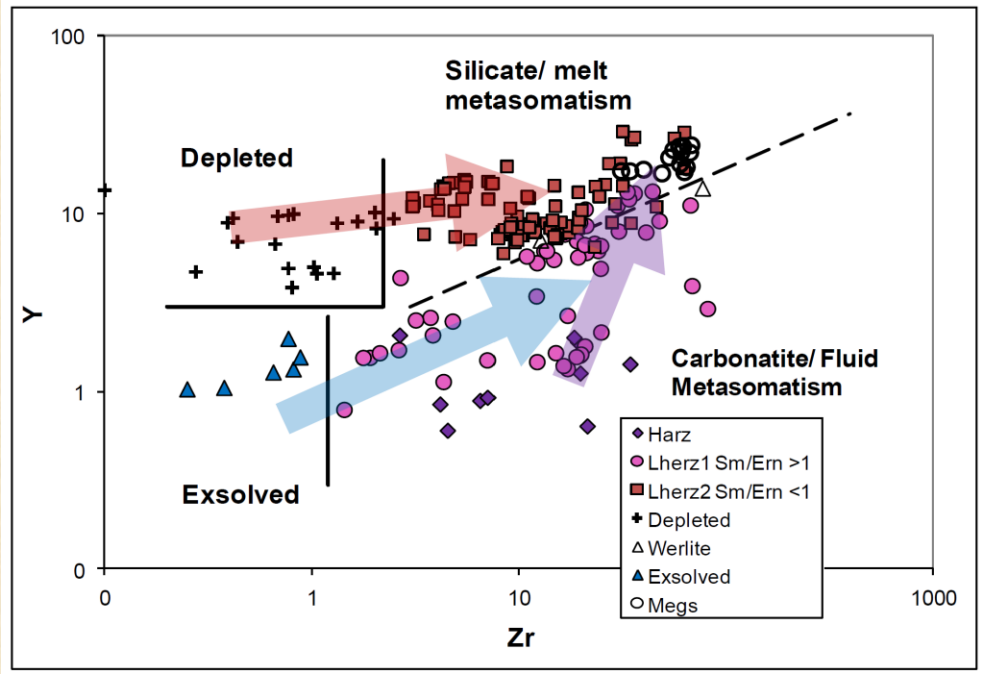


Fig 29. A genetic classification scheme for lithospheric mantle garnets based on their trace element composition (Agashev et al., 2018).

- Today, we have more precise analytical methods and can study the geochemistry of trace elements in mantle garnet inclusions in diamonds in detail.
- Studies of the Trace and Rare Earth Element composition of mantle garnets make it possible to trace its evolution during the fertilization of the lithospheric mantle as a result of metasomatic processes.
- On the Y-Zr plot are shown the main trends in the evolution of mantle garnet compositions as a result of metasomatic processes.

REE COMPOSITION OF MANTLE GARNETS

- On these graph we can see the REE composition of garnet inclusions in diamonds from the worldwide kimberlites, which indicates the stage at which these mineral inclusions are captured.

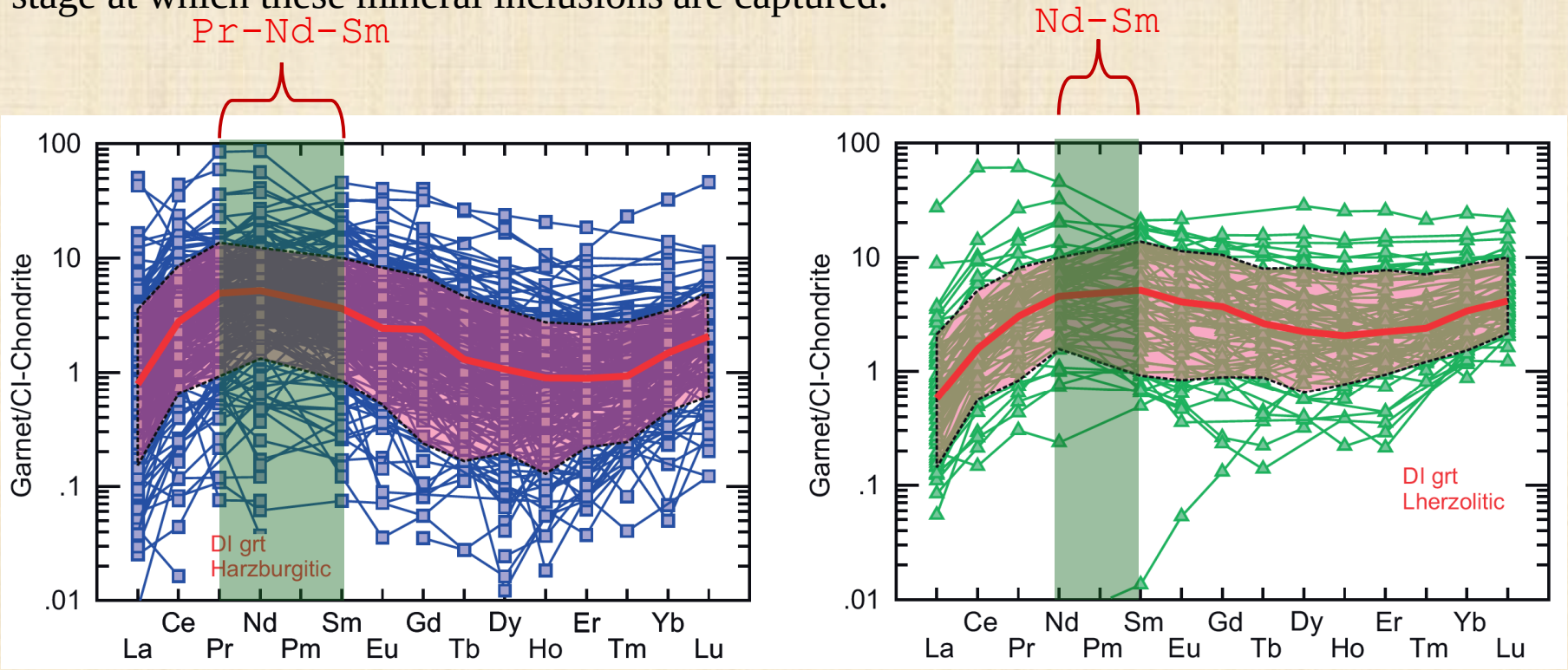


Fig 26. Chondrite-normalized REE patterns for harzburgitic (n = 223) and lherzolitic (n = 72) garnet inclusions in diamond (Stachel et al, 2022).

This fact suggests that diamond nucleation and inclusion entrapment occur at this stage. These harzburgite garnets are metasomatic in nature and formed as a result of the metasomatic interaction with the carbonatite fluids/melts.

REE COMPOSITION OF MANTLE GARNETS AND METASOMATIC PROCESS

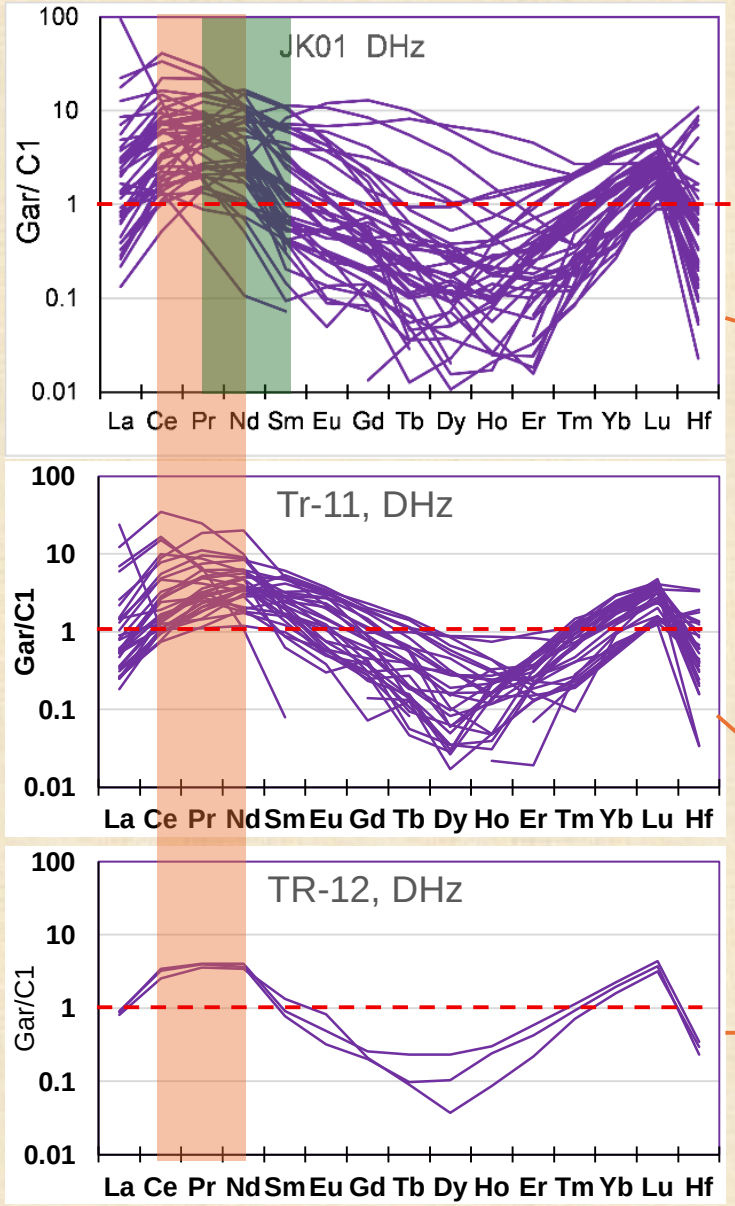


Fig 27. Chondrite-normalized REE patterns for kimberlites.

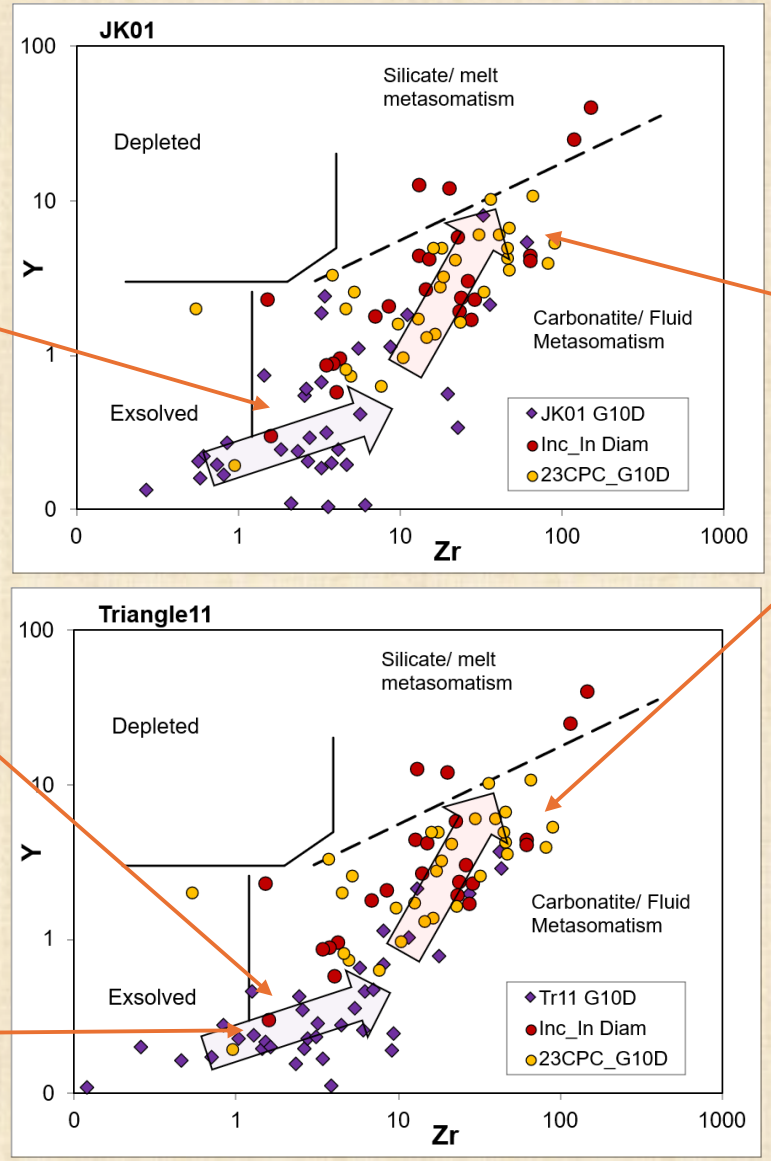
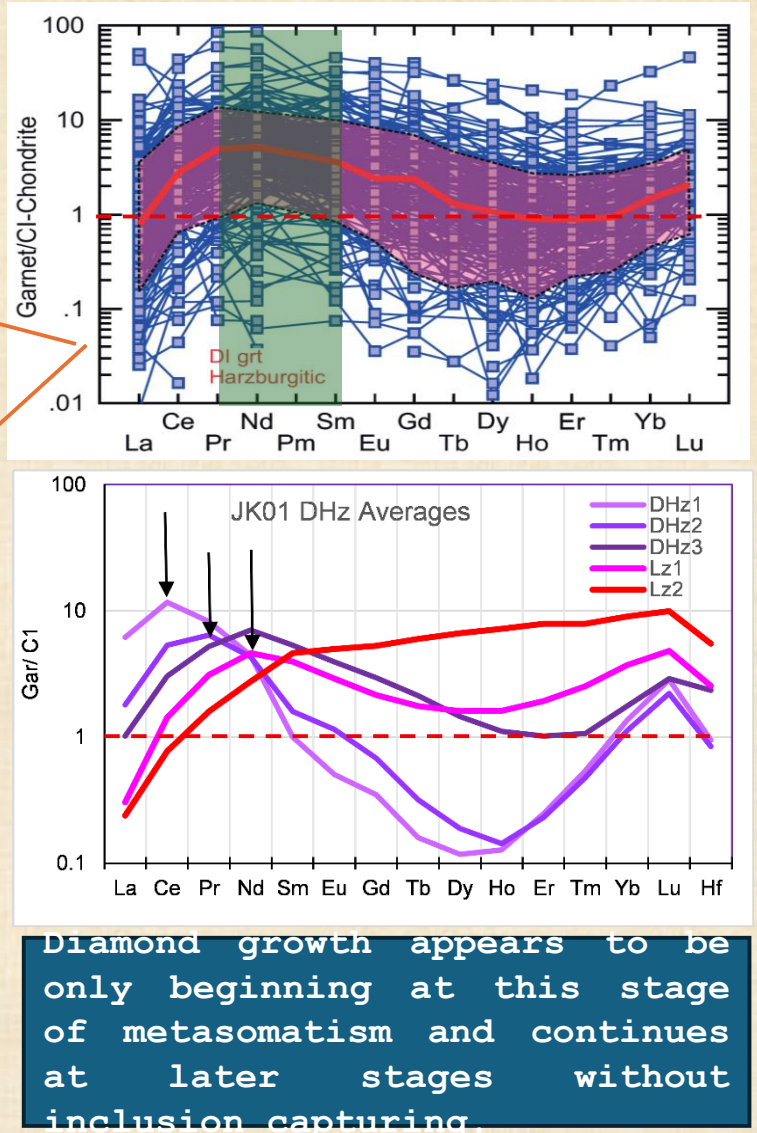


Fig 28. A genetic classification scheme for lithospheric mantle garnets based on their trace element composition (Agashev et al., 2018).



Diamond growth appears to be only beginning at this stage of metasomatism and continues at later stages without inclusion capturing.

Fig 29. Chondrite-normalized REE patterns for harzburgitic garnet inclusions in diamond (Stachel et al, 2022).

REE COMPOSITION OF MANTLE GARNETS

- Thus, we see that most garnet inclusions in diamonds were trapped at later stages of metasomatism compared to the early stages recorded in the garnets of the Tr11, Tr12 and JK01 kimberlites.
- This means that diamond growth requires a maturation stage with further input of carbon-bearing metasomatic agents.
- For example: in highly diamondiferous pipes in Siberia, such as Inter and 23rd Congress of the Communist Party of the Soviet Union, harzburgite garnets of the diamond association exhibit peaks of Nd-Sm and Gd to Tm group contents above the chondrite unit, which also indicates more advanced stages of metasomatism.

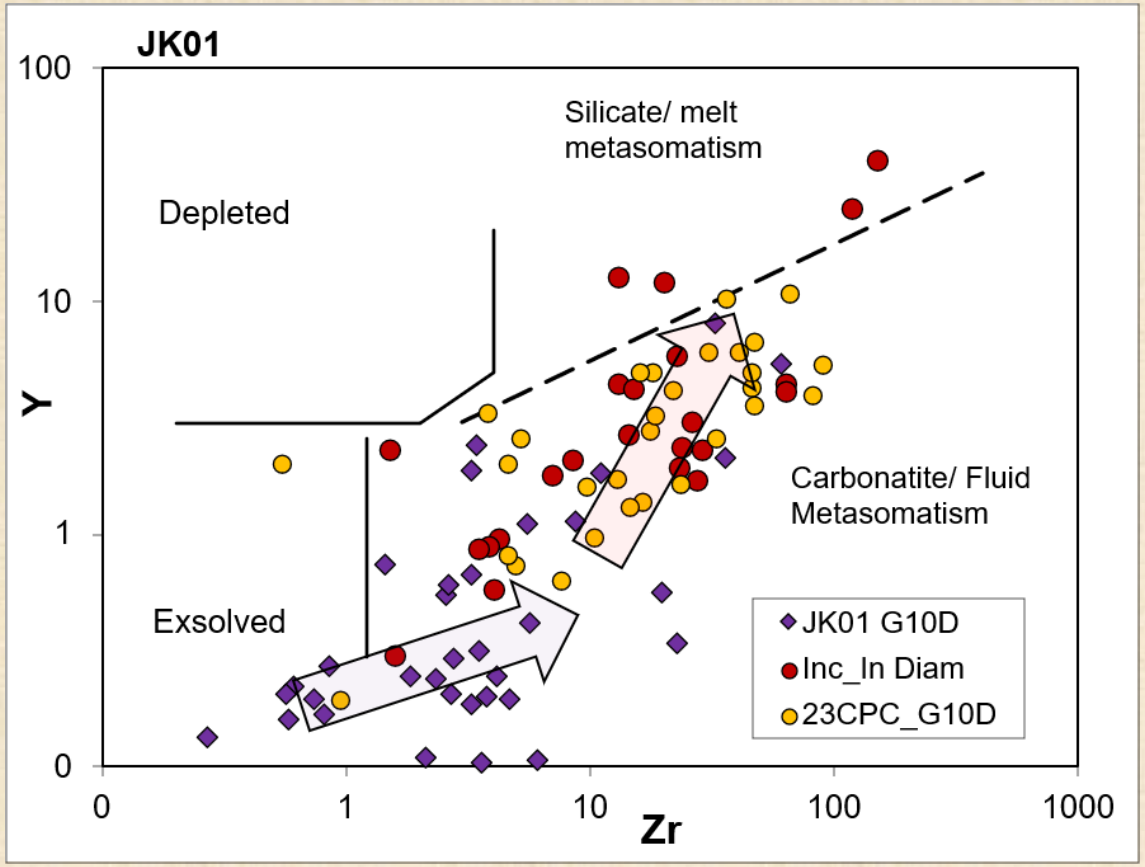


Fig 29. A genetic classification scheme for lithospheric mantle garnets based on their trace element composition (Agashev et al., 2018).

Thus, the low diamond potential of the Tr11, Tr12 and JK01 pipes is due to the cessation of fluid flow, and therefore the carbon necessary for diamond crystallization, during the early stages of metasomatism in the lithospheric mantle beneath these kimberlites. Consequently, diamond growth ceased early on. The volume of incoming fluid was likely also small, as the garnet contents of the kimberlites are also low.

Thank you for attention!