Appendix 7. Paper by Nikolay Kharkov entitled: “Technological processes’ peculiarities of mineral raw materials treatment used to substantiate the unique character of “Norilsk Nickel” products”

Technological processes’ peculiarities of mineral raw materials treatment used to substantiate the unique character of “Norilsk Nickel” products

As is clearly seen from Dr. E. Naldrett’s works and his last analytical reports prepared for the Council on independent expertise of the Complex methodical technique, (Appendix 1.) Norilsk ores have a number of specific peculiarities attaching them a unique character as compared with world basic copper-nickel and platinum-metallic deposits. The most important unique characters are the precious metals concentrations ratio in ores, and first of all platinum and palladium concentration ratio. (See Table 1).

Table 1.

Deposit	**Pt/Pd**
Norilsk (Russia)	0,34 ÷ 0,59
Talnakh (Russia)	0,10 ÷ 0,32
Pechenga (Russia)	0,46 ÷ 0,59
Bushveld complex (South Africa)	1,0 ÷ 2,89
Great Dyke (Zimbabwe)	0,87
Stillwater (USA)	0,29
Sudbury (Canada) *Lindsley*. Massive Footwall ore *Craig*. Sublayer; Footwall ore	0,61 ÷ 1,81 0,41 0,18; 0,12

Generalized data, covering the main world PGM deposits, on platinum and palladium ratio (rounded-off values to the second significant figure after point) are presented in Table 1. In order to provide better clearness these data are also presented as a graph in coordinates Pt/Au; Pt/Pd.

Figure 1. Preciouse metals ratio

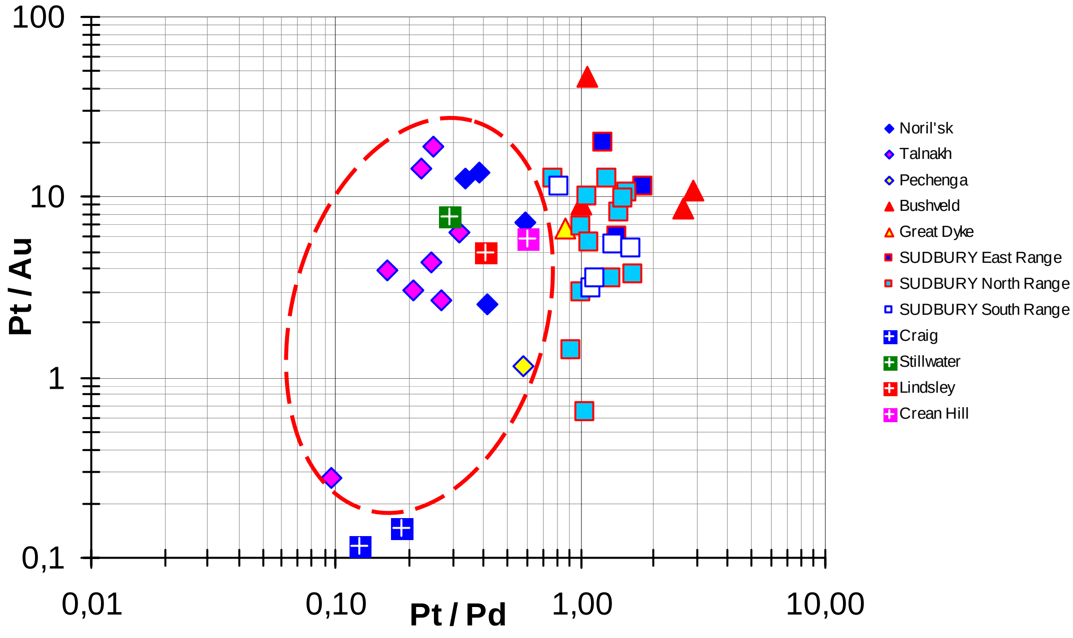
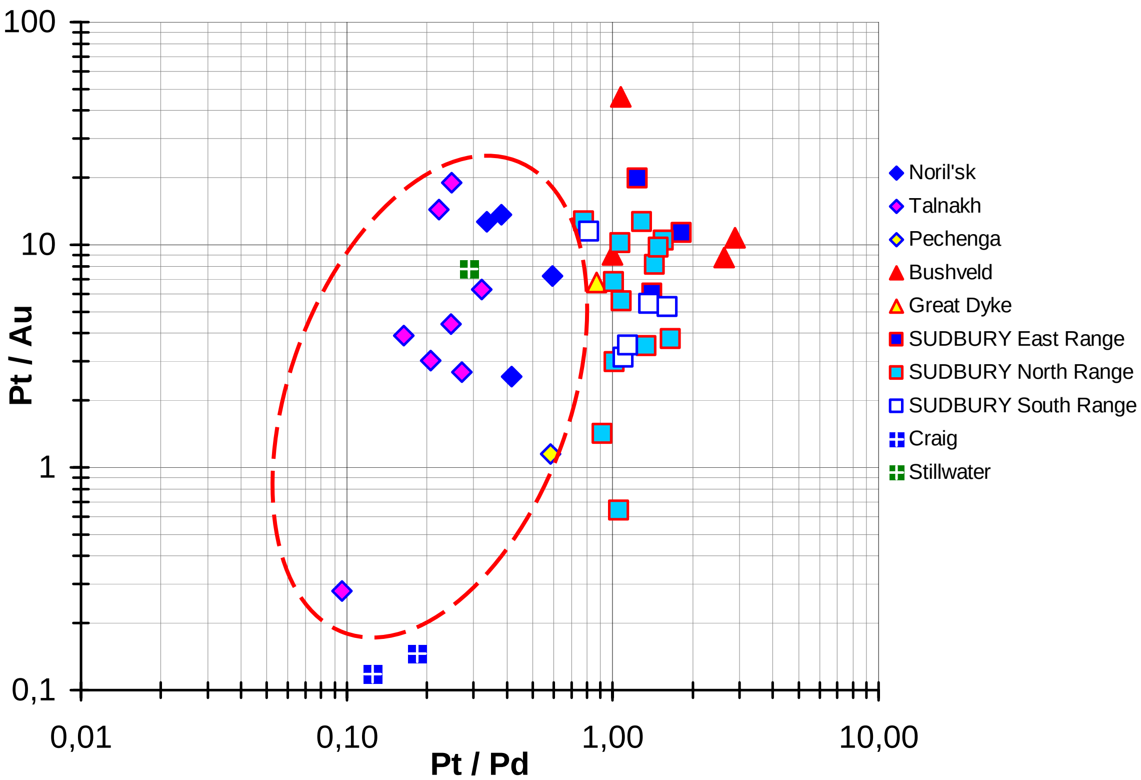


Figure.2. Preciouse metals ratio



In accordance with data presented in the analytical report prepared by the United States Geological Survey (USGS) the deposits listed in Table 1 are the sources of raw materials

for 98% world platinum group metals production. Numerical data in Table 1 are based on Dr. E. Naldrett data, information given by Dr. R. Schowstra and Kola Company Geological Survey. It worth mentioning that in some cases there is a discrepancy between Dr. E. Naldrett data and data received from other sources. In accordance to Dr. E. Naldrett data only one deposit "Pilgujarvi"-Zhdanovskoe form 5 listed is exploited. At present in accordance to the data of Kola Company Geological Survey besides "Pilgujarvi" there are two deposits Zdanovskoe-Northen (Pt/Pd = 0,460) and Zdanovskoe-Central (Pt/Pd = 0,500) which are the main sources of raw materials in Pechenga region. On this account we have presented in Table 1 interval of Pt/Pd ratio responding to the present conditions. As it is seen from Appendix 1 Bushveld Complex ores are characterized with rather wide Platinum and Palladium ratio interval (Pt/Pd = 0.578 ÷ 2,887) However the inferior border of this interval corresponds to the ores from only one "Platreef" deposit of Bushveld Complex. In accordance to Dr. R. Schowstra the average value of Platinum/Palladium ratio for Platreef deposit is about 1. "Sudbury" deposit ores are also characterized with rather wide interval of Platinum/Palladium ratio (Pt/Pd = 0,125 ÷ 1,814). The inferior border of this interval is determined by the "Sublayer"and"Footwall ore" ores of the *"Craig"* deposit. However those ores differs from ores from Russian deposits by the abnormally high gold content. As it is seen from Appendix 1 ratio between Platinum and Gold in these ores is about 0.1, and for Russian ores this ratio is in the interval between 1 and 30. In accordance to this feature *"Craig"* deposit is regarded to gold ores deposit. Thus, as it is seen from Appendix 1 and Figure 1 only ores from the Stillwater (USA) deposit and two ores from "Sudbury" province (SAR) - "*Lindsley" и "Crean Hill"* deposits do not differ from Russian ores. It is significant that mention above ores from "Sudbury" province (SAR) come to only 8% of total amount of ores extracted in this province. Because of this and taking into account that as a rule reprocessors use as raw material the mix of ores, the income of these ores to the total amount of extracted raw materials at "Sudbury" deposits could be neglected. Taking into account this assumption we have plotted graph, presented at Figure 2. From this graph it is clear that regarding the precious metals ratio the Russian ores intersect only with ores from "Stillwater" deposit.
The given above reasoning refer to ores, which are the source of raw material for PGM production.

Such ratios (with slight deviation) remain also in products of hydro- and pyrometallurgical ore processing at stages preceding separating and refining of platinum group metals. This proposition is confirmed by executed in "Norilsk Nickel" comparative investigation of elemental composition of original raw materials and semi products of technological processing represented in PGM RDB. (Appendixes 2,3) Thus, the range of platinum and palladium ratios for semi products is 0.09 – 0.45. Only semi products of the gravitation dressing, namely gravitational concentrate from enriching factory of Transpolar branch in Norilsk city was an exception, where platinum-palladium ratio made 1.44, and tailings of the gravitation dressing from Transpolar branch with platinum-palladium ratio is 1.08. But these products could not be referred to as "at-risk" products because of the following:
- the volume of their production is very small;
- very low concentration of precious metals.

It is possible that single semi products with anomalous ratio of PGM could take place also with producers in SAR and other countries. Under the present condition when the united world RDB does not exist, referring the named above so called "exception" products, it is important, that producers should establish the exchange of information about the existence of this type of products and their physicochemical characteristics.

Not having a direct information about chemical composition of semi-finished, intermediate products of South African origin, we, non the less, came to the conclusion that platinum group metals ratios in the processing of original raw materials in South Africa as in Russia practically do not change too; in any case, the spheres of these indicators changes do not intersect the products obtained from ores from different regions.

To confirm this proposition we may cite following general arguments. (Here are used materials of Mr. R. Schowstra's presentation made during a joint Russian-South African seminar/workshop in Johannesburg in March 2006, and the edition "Metallurgy of precious metals", Iou.A. Kotliar, M.A. Meretukov, L.S. Strizhko – Moscow, 'Moscow Institute of Steel and Alloys', 2005).

In the practice of platinum metals extraction single-type ore enrichment processes are applied: gravitational, flotation, pyrometallurgical, hydrometallurgical.

Gravitational PGM concentrates obtained in the gravitational enrichment process, depending on the summary volume of platinum metals, either are matte melted, or are directly sent to the final stages of hydrometallurgical enrichment. By gravitational enrichment the ratio Pt to Pd grows 3-4 times and this stresses this differentiating feature between Russian and SAR ores even more.

As to flotation enrichment of ores from Bushveld Complex the main purpose was the maximum extraction of PGM minerals, ensuring minimal technological losses. So in the process of flotation enrichment the Pt/Pd ratio practically does not change.

By smelting the flotation concentrates to matte processes of platinum metals, separation does not also take place. It is worth mentioning that by this technological operation transition of Pt and Pd to matte makes 95-98% what naturally cannot generate any evident, noticeable changes of platinum to palladium ratio. This is true for the technological operation of matte conversion.

Further processing of converter matte can be carried out in two ways.

One mode – through grinding, magnetic separation and separate acid autoclave leaching of magnetic and nonmagnetic fractions. More than 90% of PGM from converter matte by magnetic separation pass into to magnetic fraction. Magnetic fraction is leached in two stages. At the first into solution comes the main portion of nickel, cobalt and additives, at the second – copper. Thus, PGM are concentrated in the insoluble residue, and their content achieves appr. 50%. By the consequent nickel and copper leaching a portion of rhodium, ruthenium and iridium, as well as a small portion of palladium go into solution thereby slightly increasing the Pt/Pd ratio.

Another mode of converter matte processing is its electrochemical dilution producing slimes. PGM is, thus, concentrating in electrochemical slimes. As was demonstrated by an investigation conducted in "Norilsk Nickel", the consistency of technological operations which result in obtaining electrolytic slimes and later PGM concentrates does not cause any evident, noticeable changes of Platinum/Palladium ratio.

The above mention reasoning are confirmed by the information given by R. Schowstra about ratios of Platinum metals for key products of the processing chain of PGM production in SAR: Furnase mattes, Converter mattes and PGM-rich concentrates (See Tables 2 - 4).

Table 2. Platinum metals ratio for Furnase mattes

	Pt	Pd	Rh	Au	Pt:Pd
	Percentage distribution				Ratio
Anglo Platinum (Waterval)	**58**	**32**	**8**	**2**	**1.8**
Anglo Platinum (Mortimer)	**59**	**31**	**8**	**2**	**1.9**
Anglo Platinum (Polokwane)	**51**	**39**	**7**	**3**	**1.3**
Lonmin	**61**	**28**	**9**	**2**	**2.1**

Table 3. Platinum metals ratio for Converter mattes

	Pt	Pd	Rh	Au	Pt:Pd
	Percentage distribution				Ratio
Anglo Platinum (Waterval)	**58**	**32**	**8**	**2**	**1.8**
Anglo Platinum (Mortimer)	**59**	**31**	**8**	**2**	**1.9**
Anglo Platinum (Polokwane)	**51**	**39**	**7**	**3**	**1.3**
Lonmin	**61**	**28**	**9**	**2**	**2.1**

Table 4. Platinum metals ratio for PGM rich concentrates

	Pt	Pd	Rh	Au	Pt:Pd
	Percentage distribution				Ratio
Impala Platinum	**56**	**34**	**8**	**2**	**1.7**
Anglo Platinum	**58**	**32**	**7**	**2**	**1.8**
Lonmin	**62**	**28**	**8**	**2**	**2.2**
Northam Platinum	**61**	**30**	**7**	**2**	**2.0**

Thus, it is established that by processing of ores from different Russian and SAR deposits, fields into PGM concentrates the Pt/Pd ratio indicator does not change substantially (excluding products of gravity dressing), thereby certifying that this sign is a glaring and stable indicator of “Norilsk Nickel” products specificity.
And what is more, in our firm belief, technological processing operations of original mineral raw materials into PGM concentrates are only promoting, attaching new (besides the precious metals ratio) individualizing distinguishing features to “Norilsk Nickel” products.
It is connected, first of all, with the fact that in the similar operations (flotation, matte smelting, matte conversion etc.) the technological parameters of these processes are chosen considering the specific peculiarities of original raw material composition. Thus, a different original raw material determines a different regulation, order of following technological processes. As for the flotation enrichment processes, it is the chemical

reagents composition, pulp pH; for melting operations – charge chemical composition, temperature and process duration; for matte conversion processes – temperature and process duration, cooling rate etc.

Secondly, single-type operations (flotation, matte smelting, matte conversion, leaching, electrolytic refining etc.) at enterprises in different countries (and even at different enterprises of the same country) take place under different operating conditions and use different technological equipment. In any case, regarding the technology and equipment of "Norilsk Nickel", which has never been passed to any foreign enterprise we may claim this with a 100% assurance.

The differences in the composition of original raw materials, applied technological mode and in used technological equipment have an unavoidable effect on the semi products characteristics, which are determined through the Complex Analytical Procedure: total elemental composition, phase composition and allotment of particles into groups with similar elemental composition. It is essential to mention that according to the Complex Analytical Procedure, total elemental composition of every product from the RDB is characterized by the quantitative content of 30 elements; the phase composition is characterized by availability and intensity of 10 X-ray diffraction peaks on the diffractogram on average; the collection of particles of product substance is characterized by availability and weight content of 5 groups of particles on average, each of which is characterized by quantitative content of not less than 5 elements.

Reasoning from general principles of mathematical statistics and without citing concrete mathematical calculations, one may claim that the probability of two products made in enterprises of different countries having similar totalities of aforesaid characteristics is near zero.

As a case in point we present the results of contrastive analysis of similar types of products manufactured by Norilsk Nickel (Russia) and Stillwater (USA). As it is seen from Table 1 the initial ores of these Companies has overlapping meanings of the Platinum metals ratio. However, fundamentally different technology used for obtaining and further processing of Converter mattes lead to the fact that Norilsk and Stillwater semi products sharply differs by their chemical characteristics (Tables 5 and 6). For example Stillwater Converter mattes differs from corresponding Norilsk products by the sufficiently higher Gold and Platinum metals concentration. Stillwater PGM-concentrate having approximately the same PGM concentration as PGM-reach Norilsk products (KP-1 concentrate, secondary slime before leaching and washing and scrap washing slime) has several times higher concentrations of Iron, Rhodium and ten times lower concentration of Silver.

Table 5.
Comparison of Converter mattes elemental composition (mass %).

Element	Copper-nickel Converter matte NMZ	Copper-nickel Converter matte NZ	Copper-nickel Converter matte Public Corporation "Kolscaj MMC"	Converter matte SMC TBRC MATTE
Ni	44.4 - 45.8	34.2 - 35.6	41.4 - 42.9	44.1
Cu	26.9 - 27.4	38.8 - 39.1	26.0 - 28.0	28.2
Au	0.0002	0.0004	0.0002 - 0.0004	***0.021***
Ag	0.010	0.011 - 0.013	0.009 - 0.010	0.026
Pt	0.002 - 0.003	0.005 - 0.007	0.0009 - 0.0022	***0.8***
Pd	0.014 - 0.015	0.02 - 0.02	0.005 - 0.013	***1.21***
Rh	0.0004 - 0.0007	0.0007 - 0.0010	0.0003	***0.07***
Ru	0.0001 - 0.0002	0.0002 - 0.0003	0.0001 - 0.0001	***0.004***
Co	1.2 - 1.5	0.9 - 1.0	1.0 - 1.4	0.45
Fe	2.8 - 3.0	2.5 - 2.6	2.8 - 3.0	2.07
S	15.3 - 22.0	15.9 - 21.5	16.8 - 17.9	22.1
Se	0.013 - 0.023	0.02 - 0.03	0.03 - 0.07	0.07
Te	0.002 - 0.004	0.003 - 0.007	0.002 - 0.004	0.05
As	0.0014 - 0.0028	0.005	0.004 - 0.057	0.025
Pb	0.009 - 0.074	0.010 - 0.108	0.08 - 0.11	0.20
Sn	0.0005 - 0.0013	0.0005 - 0.0009	0.0011 - 0.0041	0.001
Sb	0.0003 - 0.0004	0.0006 - 0.0011	0.0002 - 0.0013	0.04
Ba	0.003	0.003	0.003	0.005
Cr	0.0002	0.0003	0.0007	0.01

Table 6
Comparison of the "rich products" elemental composition (mass %).

Sample code	Concentrate type KP-1	Secondary slime before leaching and washing	Scrap washing slime	PGM SMC PGM FILTERCAKE
Ni	0.3 - 1.0	2.8 - 6.2	1.5 - 1.8	2.66
Cu	0.7 - 4.1	1.3 - 9.5	2.3 - 3.1	4.94
Au	2.6 - 3.1	1.5 - 2.8	2.3 - 3.0	0.54
Ag	7.2 - 14.3	2.9 - 11.0	7.2 - 12.0	***0.29***
Pt	10.8 - 13.6	8.4 - 12.6	11.7 - 14.2	13.9
Pd	41.9 - 51.1	29.5 - 47.7	41.9 - 49.4	25.4
Rh	0.2 - 0.4	0.08 - 0.28	0.3	***1.53***
Ru	0.06 - 0.14	0.04 - 0.19	0.12 - 0.17	0.011
Ir	0.03 - 0.06	0.02 - 0.10	0.05 - 0.11	0.031
Co	0.011 - 0.028	0.09 - 0.18	0.04 - 0.05	0.16
Fe	0.2 - 0.7	1.2 - 2.1	0.9 - 1.5	***10.4***
S	0.6 - 2.5	4.3 - 6.1	1.2 - 2.1	7.1
Se	1.1 - 2.9	0.9 - 2.0	1.4 - 3.1	2.52
Te	2.2 - 3.6	1.0 - 2.3	2.3 - 2.8	2.27
As	0.4 - 2.7	0.8 - 2.3	0.8 - 2.6	0.33
Pb	2.3 - 3.8	1.1 - 4.4	2.2 - 4.1	6.86
Sn	0.9 - 3.1	0.4 - 6.9	0.9 - 4.5	0.046
Sb	0.6 - 1.5	0.3 - 2.8	0.7 - 2.2	0.04
Ba	0.02 - 0.09	0.0013 - 0.1090	0.03 - 0.09	0.011
Cr	0.002 - 0.064	0.004 - 0.095	0.04 - 0.14	0.043

Based on aforesaid arguments, we are of the opinion that on the ground of coincidence of a "suspect, shady" material's characteristic totalities with characteristics of any product from the PGM RDB (considering the characteristic variability of this product by a multiple testing) one may come to the categorical conclusion about its belonging to the products from "Norilsk Nickel".