12 INTERNATIONAL PLATINUM SYMPOSIUM
FIELD TRIP 2: PGM PLACER DEPOSITS AND THEIR SOURCES IN THE ULTRAMAFIC AND ALKALINE ROCKS OF THE CONCENTRICALLY ZONED KONDYOR MASSIF, FAR EAST, RUSSIA

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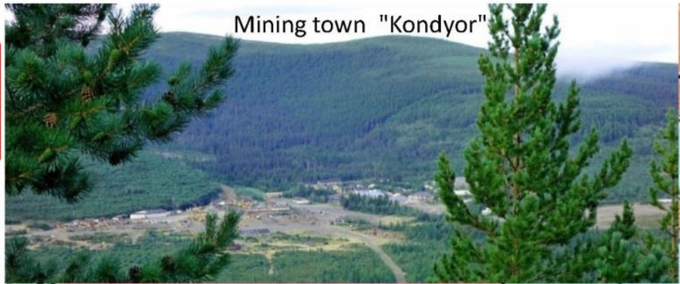
1. PROGRAMM

12 International Platinum Symposium
<u>Field trip 2</u>: PGM placer deposits and their sources in the ultramafic and alkaline rocks of the concentrically zoned Kondyor massif, Far East, Russia



Date: from 1 to 8 August, 2014
Period: pre-symposium field trip
Maximum number of the participants: 15
Estimated fee: 800- Euro
Note: The excursion fee includes flight Khabarovsk – Mar-Kyuel - Khabarovsk (personal tickets will be available), issue of a guide tour, transfer from airport to Khabarovsk.
JSC "Artel prospectors Amur" will provide transfer, services and food at the mining town "Kondyor" for the tour participants as a sponsorship.

<u>Schedule</u>

<u>1st August – Arrival</u> of the tour participants in Khabarovsk and hotel accommodation.

<u>2nd August – Three hours flight</u> from Khabarovsk to settlement Mar-Kyuel (Ayano-Maisky district) on the board of "An-26" aircraft by "Amur" Airline Company.
Four hours transfer on the board of passenger truck "Ural" from Mar-Kyuel to the mining town "Kondyor" through taiga crossing numerous rivers and hills.
Note: Accommodation at the hotel of mine "Kondyor" (2- and 3-bed room). For the tour participants the "Russian bath" will be available.

The concentrically zoned Kondyor massif

The Kondyor PGM placer deposit, was discovered and explored in 1979–1988 , in 1985 company commenced operation of this deposit. The placer, 60 km in length is located in the Kondyor and Uorgalan valleys of the fourth to fifth orders. Prospecting resources in placers were stated to amount over 100 tons of platinum. PGM-bearing sands are hosted in near-gutter parts of Pliocene to Lower Pleistocene, Middle Pleistocene, Upper Pleistocene, and Holocene alluvial sediments of valleys, terraces, and terrace ridges.

Schedule

3rd to 6th August – the geological routes, tour transfer of the participants to the outcrops will be by the passenger track "Ural", the everyday average route length around 50 km. *Note: Kondyor area has a continental climate. Daytime temperatures in early August are about +20-25 °C, and +10-15 °C at nighttime; light rains are possible. During the geological routes, participants will pass through several brooks, and it is advisable to have a raincoats and a rubber boots.*

Day 1 (3rd August) – The unique alluvial deposit of platinum group metals Kondyor-Uorgalan

Alluvial deposits in inner part of Kondyor ridge:

- 2nd order watercourse – Appendix brook

- 3rd order watercourse – Begun brook

- 4th order watercourse – Kondyor river

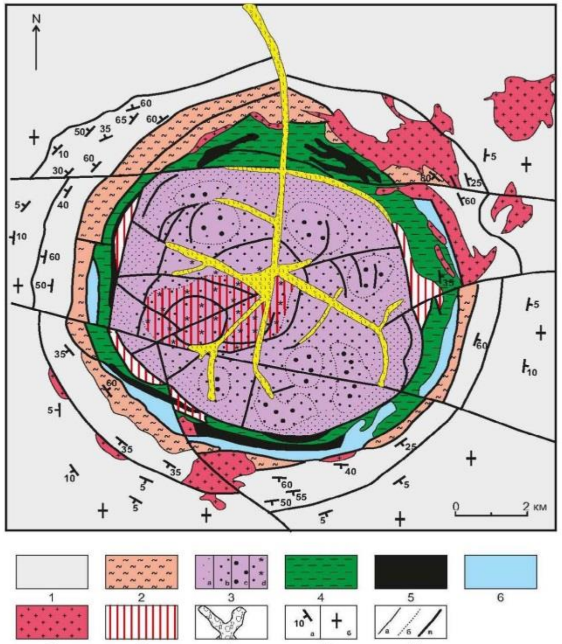
Alluvial deposits at the cross of Kondyor River and Kondyor ridge.

Alluvial deposits behind Kondyor ridge.

Alluvial deposit on Uorgalan River and examination of slime-concentration devices.

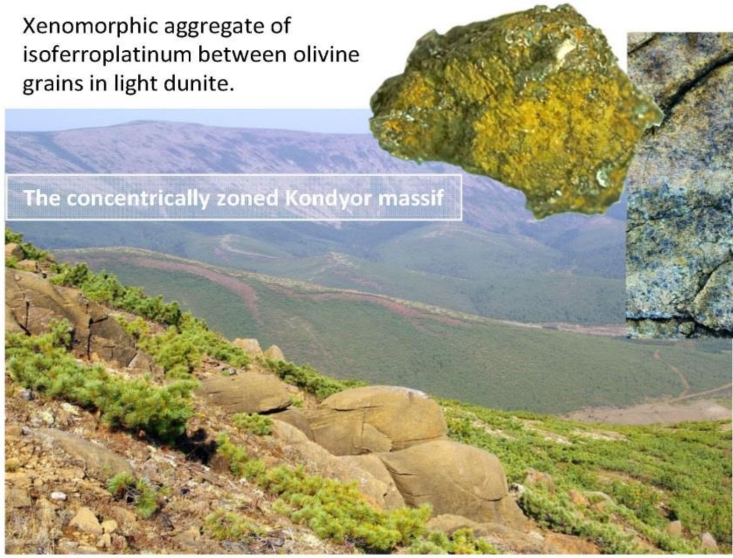
Slime-concentration of the mining town "Kondyor"

The first nugget of isoferroplatinum "Birthday", weighing 73.5 g., that was found in the Kondyor river bet during prospecting on the 26-th of August, 1981.

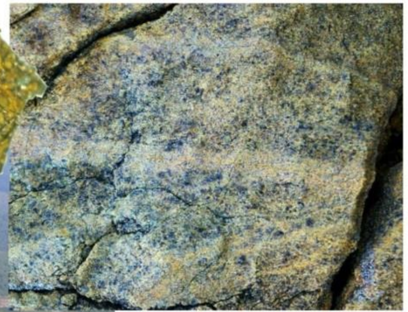


Geological sketch map of the Kondyor massif (after geological maps on scales of 1:25000 compiled by the Dal'geologiya Regional Geological Survey). (1) Middle Riphean siltstone and sandstone; (2) Early Archean gneiss, crystalline schist, marble, calciphyre and granite; (3, 4) ultramafic rocks of the Neoproterozoic (?) Kondyor complex: (3) dunite: (a) fine-grained, (b) porphyritic, (c) pegmatoid, and (d) magnetite-bearing porphyritic (altered in the Mesozoic); (4) pyroxenite ; (5–7) igneous rocks of the Aldan Mesozoic complex: (5) koswite (titanomagnetite–pyroxenite) , (6) gabbro, (7) monzodiorite; (8) zoned metasomatic rocks; (9) PGM placer; (10) inclined (a) and horizontal (b) beds; (11) geological boundaries (a), facies boundaries (b), and faults (c).

Xenomorphic aggregate of isoferroplatinum between olivine grains in light dunite.



Dunite is inhomogeneous in composition (variable contents of Fe, Ca, and Ni) and grain size of olivine, distribution and composition of chrome spinel, and degree of recrystallization.



Dunite with large black olivine containing μm sized inclusions of Cr spinel and Cr magnetite.

<u>Schedule</u>

<u>3rd to 6th August – the geological routes</u>

<u>Day 2 (4th August) – Geology</u> of the ultramafic and alkaline rocks of the concentrically zoned Kondyor massif
Examination of the outcrop of Proterozoic and Archean host rocks – diorites, skarns, a complex of alkaline rocks and) koswite. Location - canyon of the Kondyor Ridge.
Examination of the outcrop of olivine pyroxenites, wehrlites, dunites. Location - Trehglavy brook – Kondyor river – Korotysh brook.

Skarns of the Kondyor Ridge

Pegmatoid syenite

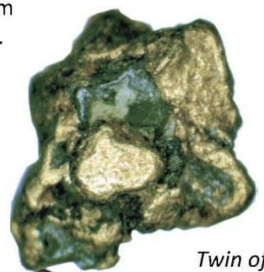
<u>Schedule</u>

<u>3rd to 6th August – the geological routes</u>

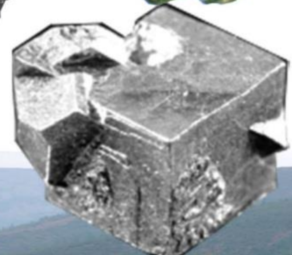
<u>Day 3 (5th August) – Primary mineralization</u> in dunites and chromitites. Location – Maliy and Begun brooks.

<u>Day 4 (6th August) – Primary mineralization</u> of koswite and alkaline pegmatites, its metasomatic formation in dunites. Location – Begun, Yuzhniy and Anomalny brooks.

Xenomorphic aggregate of isoferroplatinum are cemented chrome spinel (black) in ore.



Aggregate of native gold on the surface of cubic crystals of isoferroplatinum.



Twin of cubic crystals of isoferroplatinum from Early Cretaceous titanomagnetite–biotite–amphibole–clinopyroxene metasomatic rocks

PGM-rich chromitite of dunite.

Dunite open pit.

Koswite, alkaline pegmatites, its metasomatic formation in dunites (Anomalny brooks).

The PGM at the Kondyor deposit consists mainly of monomineralic segregations of isoferroplatinum. An insignificant amount of PGE occurs as single crystals or twins of isoferroplatinum, sperrylite, laurite, coopperite, native osmium. Minor PGM (tetraferroplatinum, tulameenite, native iridium) and more than 45 rare occur as inclusions hosted in or intergrown with isoferroplatinum grains. Five rare PGM have been described in the Kondyor deposit for the first time: cuproiridsite, cuprorhodsite, ferrorhodsite, konderite and bortnikovite.

<u>Schedule</u>

<u>7th August – Transfer of the participants</u> from mining town “Kondyor” to settlement Mark-Kuel, flight to Khabarovsk and hotel accommodation.

Note: Baggage of every participant during the flight Mark- Kyuel – Khabarovsk, should not exceed 20 kg, all the geological samples must be packaged in a separate item (box or bag).

<u>8th, 9th August – Flight Khabarovsk – Yekaterinburg</u>.

<u>Organization and execution of the scientific part of the tour:</u>

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Sergey Petrov, Ph.D, St. Petersburg State University (St. Petersburg)
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Olga Yakubovich, Ph.D, IPGG RAS (St. Petersburg) - Secretary

<u>Organization and responsibilities in the mining town "Kondyor"</u> – the employees of JSC "Artel prospectors Amur"

<u>With any questions concerning the field trip, please contact</u>:
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<u>Terms and Conditions:</u>

1. Participation will be confirmed on receipt of payment.
2. Preference will be given to registered IPS delegates.
3. Cancellations must be received by the e-mail: vladimir@itig.as.khb.ru; olya.v.yakubovich@gmail.com.
4. Any refunds issued will be subject to approval by the organizing committee.
5. Cancellations received before April 30, 2014 will receive a 100 % refund minus a banking fee.
6. Cancellations received between April 30 and May 31, 2014 will receive a 50% refund minus a banking fee.
7. No refunds will be issued after May 31, 2014.
8. In the case of full trip cancellation by the organizers, a full refund will be issued.
9. All participants should have their own personal insurance cover for general travel insurance, personal liability, medical cover and dangerous activities cover. A copy of confirmation of insurance must be submitted to the organizers prior to participating in the field trip.

2. OJSC "ARTEL PROSPECTORS AMUR"

AS Amur is the assignee of AS Aldan. AS Aldan was formed in 1969 as a part of the industrial enterprise "Aldanzoloto". Under the leadership of V. I. Tumanov AS Aldan started the development of the placer of the Buor-Sal river on the Ket-Kap ridge in the Uchursky gold-field on the territory of the Khabarovsk region. In a taiga solitude, thanks to the unprecedented work of the AS Aldan pioneers all placers of the Ket-Kap ridge were involved in operation (more than 140 km) and explored by "Yakutgeologiya" and "Dalgeologiya" geologists. More than 1 ton of gold was supplied per year to the state.

In the middle of October, 1972 AS Aldan was subordinated to the industrial enterprise "Primorzoloto" in Khabarovsk. In 1973 AS Aldan was disbanded, and AS Amur became its major assignee with the headquarters on Vostochnoye Shosse, 10 in Khabarovsk. The headquarters of the company are now at the same place.

In the course of 1973-1990 of the production activity AS Amur got the wealth of experience of the gold placers mining. In this regard the state entrusted AS Amur to develop the unique PGM placer named Kondyor (the Kondyor-Uorgalan rivers), after the reserves approbation in 1988 by "Dalgeologiya" in the USSR state reserves committee. Since 1984 AS Amur began the in-mine sampling of the several sites of the Kondyor placer in the course of geological exploration.

At the beginning of 90th AS Amur became the open joint stock company – AS Amur, OJSC and successfully fitted into the new economic conditions. Due to the depletion of the gold placers reserves the company was one of the first in the country which actively started to develop the ore gold-bearing deposits. The design department for the construction of the several gold-extracting plants with a year-round cycle of works was created in AS Amur. The important stage was the formation of AS Amur geological exploration expedition, at that time it was the largest in the country. The Amur airline company was organized. The company developed the non-core activities on production of the consumer goods and rendering services, established the trade enterprises. There was the significant contribution of AS Amur to the social and economic development of the Ayano-Maysky region.

In 2007 AS Amur, OJSC joined the Russian Platinum group of companies. It was the new high-tech period of the company history. The Hitachi mining equipment was purchased. Due to the large tax liabilities, AS Amur continues to play an important role in the social and economic development of Khabarovsk territory and the municipal Ayano-Maysky region. The company maintains the airport in the Nelkan village and carries out the air transportation of locals. The company delivers the freights to local settlements of the Ayano-Maysky region for the hunters and reindeer herders, supports the veterans, and annually organizes the transportation of the children from the Ayan social shelter on vacation.

Today AS Amur is the leader in production of the precious metals in the Far Eastern region and is one of ten largest Russian mining companies. As for platinum production volumes AS Amur takes the second place after "Norilsk Nickel". In total for years of the production activity the company produced more than 170 tons of platinum and gold. Now the exploration works on the ore platinum are conducted. The average annual number of employees of the company is about 1300 people.

Now the territory of the primary production activity of AS Amur includes South Yakutia (Tommot and Belkachi transshipment bases) and the Ayano-Maysky region of the Khabarovsk territory. These are the almost impassable mountain areas with the severe climate. In winter it is possible to move across the region only by the internal winter roads. The length of the main road by which the delivery of freights on the Tommot-Kondyor route is conducted - is more than 800 km. In summer the delivery of freights is possible only by water to the Belkachi transshipment base on the bank of the Aldan river. For this purpose the company uses its own fleet and the river tankers of the third-party organizations. Various freights from the Belkachi base and the Mar-Kyuel airport are transported by the motor transport on the dirt technical roads. Transferring of the company employees to the Ayano-Maysky region is carried out by the air transport via the Mar-Kyuel airport.

The main mine site of AS Amur– the Kondyor placer is located in 90 km to the west of the Nelkan village. The number of workers is about 800 people. On the mine site there is the significant amount of processing units, dump trucks and excavators, heavy bulldozers, wheel loaders, diesel power plants and etc. Besides the advanced equipment and the well-functioning mining technology the operations support facilities were created where there are workshops for the high-quality maintenance of equipment, fuels and lubricants warehouses, oxygen station.

Due to the beginning of the placer mining in the Uorgalan river in 2005 it was decided to construct the new administrative and household complex - the Uorgalan camp. In the camp there are good living conditions for workers, three meals per day, there are sport complexes, saunas, systems of satellite television, cellular communication. In autumn 2014 the commissioning of the air strip is expected in close proximity to the Uorgalan camp for acceptance of An-24, An-26 and An-12 aircrafts.

The final product of the mine operation is «schlich PGM». At the beneficiation plant the jigging technology is applied. While processing on the shaking table the «schlich PGM» is recovered from a heavy concentrate. In the last ten years the average production value of the mine is at the average rate of 3,6 – 3,7 tons of the «schlich PGM».

Taking into account the becoming more complicated mining conditions AS Amur closely cooperates with the leading scientific and production companies: IRGIREDMET, TOMS and others.

3. THE KONDYOR ALLUVIAL PLACER OF PLATINUM METALS

First information about potential commercial content of platinum in upper streams of Kondyor River were obtained in 1958 by the «Aldanian Expedition of VAGT». During the period of 1979-1988 the Kondyor placer deposit of PGE were explored and studied in the detail by the group of specialists of the Ayano-Mayskaya Geological Explorating Expedition «Dalgeologiya». The «Amur» crew started the exploitation of the deposit in 1984.

Based on the balance reserves of platinum metals, which are more than 100 tons, the Kondyor deposit may be considered as an important one (unique). Structurally it is a persistent lengthwise and across the width alluvial placer where ore minerals are distributed unevenly [Methods..., 1992].

The placer is located along the 4-th and 5-th order valleys of the Kondyor and Uorgalan rivers. Its total length, including the parts situated in the 1-st, 2-d and 3-d order streams of the Kondyor River, approximates 60 km. The average width of the placer is 360 m. Usually the platinum bearing «sands» are parts of the alluvial deposits of different ages that lie along bedrocks of the valleys, terraces and bars. The average thickness of the platinum-bearing sands of the deposit is 2.4 m, while the «overlapping peats» are up to 5.5 m thick. Productivity of the metal-bearing sands corresponds to the ore average concentration range from 2 to 5 grams in 1 cubic metre. 65% of resources are located in the valley of Kondyor river, 23% – Uorgalan river, 6% – in streams of the 3-d order (Begyun and Trezubets brooks), 6% – in streams of the 2-d order (Trexglaviy, Korotish, Pryamoy, Anomalniy, Uzniy, Left Begyun, Right Begyun, Maliy, Appendix, Dvuglaviy brooks), and less than 1% in streams of the 1-th order.

Platinum-bearing «sands» mainly consist from «schlich of platinum group minerals (PGM)», that is presented almost by 100 mineral species of Pt, Ir, Os, Pd, Rh and Ru (Table 3.1.). The sands also contain native gold (the first tens of mg/m3), native silver, titanomagnetite (nugget) and chrome-spinels (2.5-8 %), as well as harmful admixture – thorite. By the chemical and mineralogical composition the placer has been assigned to iridium-platinum and platinum mineralogical-geochemical types [Methods..., 1992, Mochalov, 1994, 1997].

The «head» part of the alluvial deposit is localized within the place of destruction of the concentrically zoned alkaline-ultramafic massif Kondyor. Within the massif primary sources of PGM are found in dunites, chromitites, olivinites, pyroxenites, kosvites, apatite-biotite-titanomagnetite-clinopyroxenite metasomatites, alkaline pegmatites and sulfide-malachite rocks. In the eluvium of originally Pt-bearing rocks large aggregates of PGMs that intergrowth with rock-forming minerals are found (Fig. 3.1. and photo of the program). Diversity of the mineral species of Pt, Ir, Os, Pd, Rh and Ru in placer is related to the genetic differences of primary sources [Geologiya…1994; Mochalov, 2000].

The massif is marked in the relief as a ring range, rising 400-500 m high above the Omnmsko-Maya highland. The range had resulted from intrusive and protrusive uplifting of the massif, that is still going on, and from selective erosion and denudation of the relatively soft alkaline and ultramafic rocks. The range itself consists of the Archean rocks, while its inner «hollow», that represents a structural-erosional depression, has been formed in rocks of the Mesozoic intrusive complexes (Fig. 3.1.). The inner slopes of the range and depression are drained by channels of different orders (1-4), forming a centripetal system with the single withdrawing valley of Kondyor and Uorgalan rivers.

The massif morphostructure and relief were formed in several stages, but only signs of the Late Cretaceous-Paleogene and Neogene-Quaternary cycles have been fixed in the relief of today. In the Cretaceous-Paleogene period the morphostructure of a central type developed from a dome to a ring form; by the end of that period the considerable truncation, relief removal and formation of the planation surface took place. The modern ring morphostructure of the massif resulted from the resumed erosion that was lasting during the stage of the latest uplift, dating back to the end of the Paleogene [Mochalov, Khoroshilova, 1998].

Table 3.1. Platinum-group minerals in placer deposits (PD) and their sources in the ultramafic and alkaline rocks (UAR) of the concentrically zoned Kondyor massif, Far East, Russia

Mineral	Established formulas	PD	UAR
1	2	3	4
Native platinum	Pt; (Pt,Fe); (Pt,Pd); (Pt,Pd,Cu)	+	+
Isoferroplatinum	$Pt_{3-x}Fe$; $(Pt,Ir)_3Fe$; $(Pt,Rh)_3Fe$; $(Pt,Pd)_3Fe$; $Pt_3(Fe,Cu)$	+	+
Tetraferroplatinum	PtFe; Pt(Fe,Cu); Pt(Fe,Cu,Ni); (Pt,Pd)(Fe,Cu,Ni)	+	+
Tulameenite	Pt_2FeCu	+	+
Hongshite	PtCu; Pt(Cu,Fe); Pt(Cu,Sn); (Pt,Pd)(Cu,Sn); (Pt,Pd)(Cu,Sb); (Pt,Au)(Cu,Fe)	+	+
Rustenburgite	$(Pt,Pd)_3Sn$; Pt_2PdSn	+	+
Tatyanaite	$(Pt,Pd,Cu)_3Sn$	+	
Niggliite	(Pt,Pd,Cu)Sn	+	
Phase 1	$(Pt,Pd)_5Cu_3Sn_2$	+	+
Phase 2	$(Pt,Pd)_2CuSn$		+
Phase 3	(Pt,Pd)(Bi,Sb)	+	
Insizwaite	$PtBi_2$	+	
Moncheite	$Pt(Te,Bi)_2$		+
Sperrylite	$PtAs_2$; $Pt(As,Te)_2$; $(Pt,Pd)(As,Te)_2$	+	+
Phase 4	$(Pt,Au,Cu)_2As_3$		+
Platarsite	$(Pt,Rh)(As,S)_2$	+	+
Cooperite	PtS;	+	+
Breggite	(Pt,Pd)S; (Pt,Pd,Ni)S	+	+
Malanite	$CuPt_2S_4$; $Cu(Pt,Rh,Ir)_2S_4$; $Cu(Pt,Ir,Rh,)_2S_4$	+	+
Phase 5	(Pt,Cu,Fe oxides)	+	+
Phase 6	(Pt,Pd,Bi oxides)	+	
Native iridium	(Ir,Os,Pt)	+	+
Phase 7	Ir_5PbS_{10}	+	
Iridarsenite	$(Ir,Pt)(As,S)_2$	+	+
Irarsite	IrAsS; (Ir,Rh)AsS	+	+
Kashinite	$(Ir, Rh)S_2$	+	
Cuproiridsite	$Cu(Ir,Rh,Pt)_2S_4$	+	+
Inaglyite	$Cu_3PbIr_8S_{16}$	+	+
Phase 8	$(Fe,Ni,Cu)_4(Ir,Rh)_2S_7$	+	
Phase 9 (hydroosmirite)	(Ir, Os, Ru, Pt oxides); $Ir(Os,Ru,Fe)O_2(OH)_2$	+	+
Native osmium	(Os); (Os,Ir); (Os,Ir,Ru)	+	+
Erlichmanite	OsS_2; $(Os,Ru)S_2$; $(Os,Ru,Ir)S_2$;	+	+
Skaergaardite	(Pd,Pt)(Cu,Fe); $(Pd,Au,Pt)_{1+x}(Cu,Fe)$		+
Phase 10	$(Pd,Pt)_2(Au,Ag)(Cu,Sn)_2$	+	
Bortnikovite	Pd_4Cu_3Zn	+	
Phase 11	$Pd_4Au_4Cu_4Bi_3$ – $(Pd,Au,Cu)_4Bi$	+	
Phase 12	$(Pd,Rh)_3Bi$	+	
Phase 13	Pd_7Bi_4; $(Pd,Rh)_7Bi_4$	+	
Phase 14	$(Pd,Rh)_4Bi_3$	+	
Phase 15	$(Pd,Au)_3Bi_2$	+	
Phase 16	$(Pd,Au,Cu,Rh)_{11}Bi_7$	+	
Phase 17	Pd_6BiTe		+
Phase 18	Pd_7Bi_2Te		+
Sobolevskite	$(Pd,Pt,Cu)_{1+x}(Bi,Te)$ - $(Pd,Pt,Cu)_{5+x}Bi_3Te_2$	+	
Phase 19	Pd_2BiTe; $(Pd,Pt)_2BiTe$	+	+
Polarit	PdBi; $(Pd,Pt)_{1-x}(Bi,Te)$ - $(Pd,Pt)_{26}Bi_{21}Te_7$	+	+
Zvyagintsevite	Pd_3Pb; $(Pd,Pt)_{3+x}Pb$; $(Pd,Pt)_{3+x}(Pb,Sn)$; $Pd_{23}(Pb,Te,Bi)_8$; $Pd_{23}(Pb,Bi,Sn)_8$	+	+

1	2	3	4
Keithconnite	$Pd_3(Te,Pb)$; $(Pd,Cu)_{19}Te_6$; $(Pd,Pt)_3(Te,Bi,Pb)$ - Pd_9Te_2Bi; $Pd_{15}Te_3(Bi,Pb)_2$	+	+
Kotulskite	$Pd(Te,Bi,Pb)$ – $Pd_5Te_2(Bi,Pb)$	+	+
Phase 20 (Stibiopalladinite?)	$(Pd,Pt,Cu)_{10}(Sb,As)_3$; $(Pd,Pt,Cu)_{3+x}(Sb,As)$;		+
Stibiopalladinite	$(Pd,Pt,Cu)_5(Sb,As)_2$;	+	
Isomertieite	$(Pd,Cu)_{11}As_2Sb_2$; $(Pd,Cu)_{11}As_2$ $(Sb,Te)_2$; $(Pd,Cu)_{11}As_2$ $(Sb,Bi,Te)_2$	+	+
Mertieite I	$(Pd,Cu,Pt)_{11}(Sb,As)_4$; $(Pd,Cu,Pt)_{5-x}(Sb,As)_{2+x}$	+	+
Mertieite II	$(Pd,Pt,Cu,)_8(Sb,Sn,As)_3$; $(Pd,Pt,Cu,)_8(Sb,Te,Sn, As)_3$	+	
Atokit	$(Pd,Pt)_3Sn$; $(Pd,Pt)_3(Sn,Pb)$; $(Pd,Pt)_{23}Sn_4Pb_3$; $(Pd,Pt)_{22}(Sn,Pb)_7$	+	+
Taimyrite	$(Pd,Cu)_3Sn$; $(Pd,Pt,Cu)_3Sn$	+	
Cabriite	$(Pd,Pt)_2SnCu$	+	
Phase 20	$(Pd,Pt,Cu)_3(As,Sn,Sb,Pb,Bi)$ - $(Pd,Pt,Cu)_9(Sn,Pb)(Sb,Bi)As$; $Pd_9SnSbAs$	+	
Phase 21	$Pd_6(Bi,Te,Sn)As$; $(Pd,Cu)_6(Bi,Te,Pb)As$		+
Phase 22	$Pd_{12}As_5$	+	
Stillwaterite	Pd_8As_3	+	
Palladoarsenide	Pd_2As	+	
Vysotskite	$(Pd,Pt)S$	+	+
Vasilite	$(Pd,Cu)_{16}S_7$; $Pd_7Cu_2S_4$	+	
Phase 23	(Pd oxides)	+	+
Phase 24	(Pd,Bi oxides)	+	
Phase 25	(Pd,Te oxides)	+	
Phase 26	(Pd,Pt,Sn oxides)	+	+
Phase 27	$(Rh,Ir)_3(Te,Pb)_4$ - $(Rh,Ir)_9Pb_2Te_{10}$		+
Hollingworthite	$RhAsS$; $(Rh,Ir,Pt)AsS$; $(Rh, Pt, Ir)AsS$; $(Rh,Pt)(As,S)_2$; $(Rh,Pt,Os,Ir)(As,S)_2$	+	+
Phase 28	$(Rh,Ir,Pt,Pb,Cu,Ni)_2(S,As)_3$ - $(Rh,Ir,Pt)_3(Pb,Cu,Ni)S_4As_2$	+	+
Cuprorhodsite	$CuRh_2S_4$; $Cu(Rh,Pt)_2S_4$; $Cu(Rh,Ir,Pt)_2S_4$;	+	+
Ferrorhodsite	$(Fe,Cu)(Rh,Pt)_2S_4$; $(Fe,Cu)(Rh,Ir,Pt)_2S_4$		
Phase 29	Rh_2S_7	+	
Konderite	$Cu_3PbRh_8S_{16}$; $(Cu,Fe)_3Pb(Rh,Ir,Pt)_8S_{16}$; $(Cu,Ni)_3Pb(Rh,Pt,Ir)_8S_{16}$	+	+
Phase 30	$(Ni,Rh,Cu,Fe,Pt,Ir)_{1-x}S$ - $(Ni,Cu,Fe)_{12}(Rh,Pt,Ir)_7S_{20}$		+
Phase 31	$(Fe,Rh,Ni,Cu,Ir)_{1-x}S$ - $(Fe,Ni,Cu)_{12}(Rh,Ir)_7S_{20}$; $(Fe,Rh,Ni,Ir,Cu,Pb)_{1-x}S$		+
Phase 32	$(Fe,Ni,Cu,Co)_{13}(Rh,Pd,Pt)_8S_{20}$	+	
Phase 33	$(Fe,Ni,Cu)_4(Rh,Ir)_2S_7$;	+	
Phase 34	(Rh,Fe oxides)	+	+
Native ruthenium	(Ru,Os,Ir)	+	
Laurite	RuS_2; $(Ru,Os)S_2$; $(Ru,Os,Ir)S_2$	+	+
Native gold with platinum	(Au,Ag,Pt); (Au,Ag,Pd); (Au,Ag,Cu,Pd); (Au,Cu,Pt); (Au,Pd,Cu); (Au,Pt,Cu)	+	+
Phase 35(Native gold?)	$(Au,Ag,Pt)_3Cu$; $(Au,Ag,Pt)_{3-x}Cu_{3+x}$	+	+
Tetraauricupride	(Au,Pt)Cu; (Au,Pd)Cu	+	+
Auricupride	$(Au,Pd)_3Cu$	+	
Native copper with platinum	(Cu,Pt); (Cu,Pt,Sn); (Cu,Pd,Sn)	+	+

Note: Table is based on author original data. Moreover I.Ya. Nekrasov et al (1994) established the following phases: $(Pd,Pt)_{10}(Pb,Bi)_3$, Pd2Ge, (Pd,Au,Ag,Ni)10(Bi,Pb)2S4; G. G. Shcheka et al, (2004) - Pd_7Bi_3.

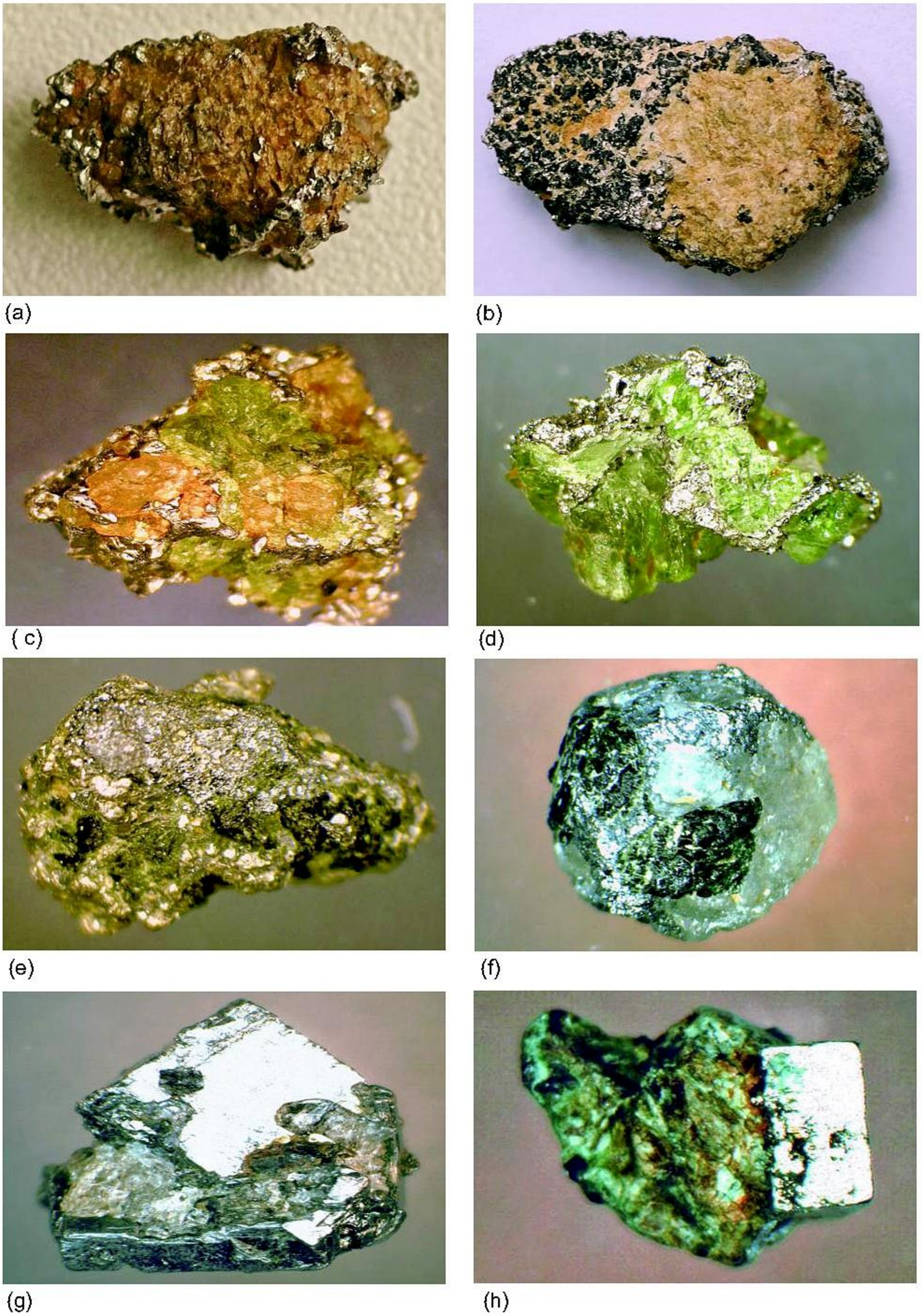

Fig. 3.1. Morphology of aggregates of PGM with rock forming minerals:
a-b olivine of dunites, b – and chromespinelide; c – diopside and olivine of wehrlites, d- diopside of clinopyroxenites, e,d – aegirine of alkaline pegmatites, d – and natrolite; g –apatite and pyroxene of apatite-phlogopite-magnetite-pyroxenite metasomatites; h – malachite and chrysocolla of sulfide-bearing metasomatites

The inherited nature of the relief stimulated frequent redeposition of the metal-bearing alluvium that, on the one hand, had led to the concentration of PGM in «sands» within the inner depression (42%) and, on the other hand, caused apart of mineral product components to be evacuated rather far beyond the ore-bearing massif (58%) -over a distance that reaches 35 kilometres.

The alluvial deposit has been subdivided into 5 complexes of different ages: Pliocene-Early Pleistocene, Middle Pleistocene, Early and the second half of Late Pleistocene, Holocene. In the case that the Pliocene-Early Pleistocene complex has remained, it stands out because of its productivity. The spatial distribution relation among the sequences of different ages, degree of its preservation, morphology of valleys, structure and thickness of loose deposits are very variable along the stretch of the alluvial placer. Seven sites can be distinguished from the head of the valley downstream according to different valley structures and various morphogenetic types of alluvial deposits (Fig. 3. 3.).

At the very head of the placer downcuttings of different ages coincide completely with the Pliocene deposits underlying the today ravine alluvium and containing «schlich PGM» that is mostly dispersed through the sequence (zone 1). In the central depression complexes of different ages are confined to the system of terrace levels transformed in bars by the processes that have formed slopes, while simultaneous horizontal shift of the floor is evident. The productivity of the alluvial placer shows a rise from high terrace levels to the floor of the valley (zone 2). The site of crossing of the ring range by the Kondyor valley displays the plane matching of downcuttings of different ages within the entrenched valley. It is responsible for practically complete destruction of more ancient metal-bearing sediments that had been redeposited on the valley floor where, in spite of minimum thickness of the sediments, the maximum concentrations of « schlich» have been observed (zone 3). Outside of the massif gradual lowering and junction of levels of different ages takes place. Firstly, they become transformed in 2 levels (zone 4), later – in 1 terrace (terrace-bar) level (zone 5), then the matching of levels within the modern floor occurs (zone 6), and, at last, little by little, their plunge is in progress and a system of buried downcuttings develops (zone 7). The deepest Pliocene-Low Pleistocene downcutting is characterized by the most thickness of the layer (up to 20 m) and highest concentrations of " schlich platinum".

By character of distribution of «schlich PGM» the Kondyor alluvial placer can be subdivided in 2 sites. The 1-st site lies within the inner part of the basin up to geological line 160 (zone 3, Fig. 3.3.), where medium- and coarse-grained fractions, as well as nugget ones are dominant. Nuggets makes up 2.5 mass percent (Table 3.2).

Table 3.2. Weighted average granulometric composition of the «schlich PGM» of the Kondyor platinum metal placer (mas. %)

Channel	Fraction (mm)							
	+10	10-5	5-3	3-2	2-1	1-0.5	0.5-0.25	-0.25
The 1 st-3d order tributaries of the Kondyor river head	5.2	4.9	3.9	3.8	28.4	24.0	26.2	3.6
Kondyor river, lines 216-160	1.5	1.5	1.8	4.5	29.3	27.3	30.1	4.0
Kondyor river, lines 216-160 and its tributaries	2.5	2.5	2.4	4.3	29.0	26.4	29.0	3.9
Kondyor river, lines 160-16	n.d.	n.d.	1.2	2.8	21.1	29.4	34.3	11.2
Uorgalan river, lines 180-120	n.d.	n.d.	n.d.	n.d.	1.1	21.6	60.5	16.8

Note. The weight average granulometric composition is determined by ordinary sieve analyses of the «schlich PGM» from 406 geological-prospecting samples and 30 operating daily observations. It has been calculated in proportion to the placer reserves. n.d. – not detected

The «heavy concentrate platinum" contents are noteworthy for high linear produc-tivity that may be as much as several hundred grams per 1 cubic metre. The sands contain a rather high percentage of a pebble material (for a fraction +100 it exceeds 20%, including boulders which are 6 %). The yield of fine grained fractions is insignificant (the first percent). The second site is

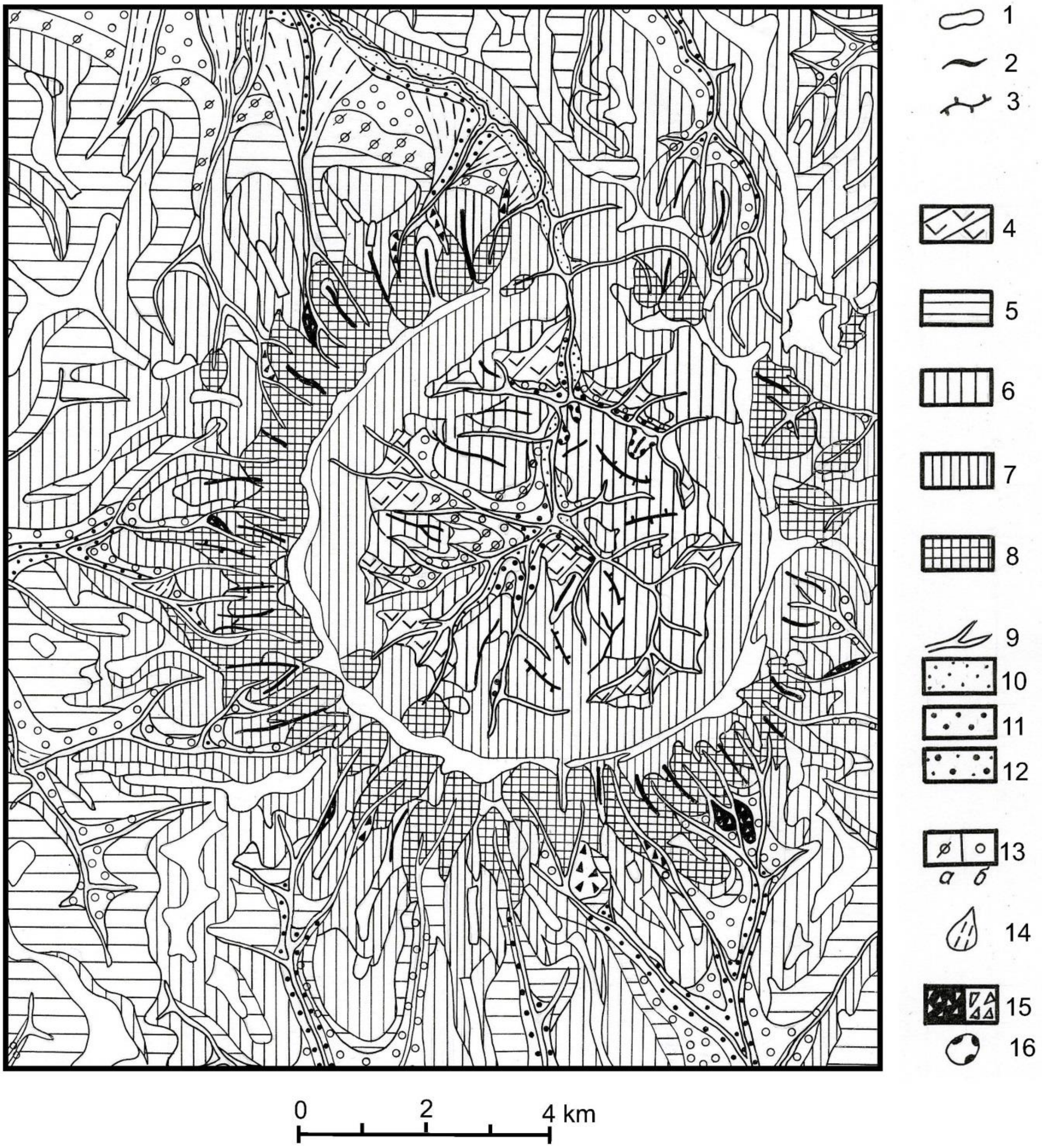

Fig. 3.2. Geomorphological map of the Kondyor ring range
1-8-forms and elements of forms of the structural-denudational relief:1-3 - apical surfaces: 1 - planated interfluve surfaces, 2 - round-apical intertluve surfaces, 3 - spine-apical ranges; 4-8 - slopes: 4 - solifluction slopes and defluction-deserption ones of 5-15 steepness, thickness of loose deposits is over 2m, 5 - deduction and defluction-solifluction slopes of 5-15 steepness, thickness of loose deposits is less than 2rri 6 - defluction slopes of 15-25 steepness, thickness of loose deposits is less than 2m, 7 - talus and defluction-talus slopes of 25-35 steepness, thick-ness of loose deposits is up to 5m, 8 - downfall-talus slopes with steepness exceeding 35, thickness of loose deposits is up to 5m;9-12 - forms and form elements of a fluvial relief: 9 - low floodplain of less than 0.5m height, 10 - high floodplain of 0.5-2m height, 11 - the first terrace above the floodplain of 2.5-8m height, 12 - the second terrace above the floodplain of 6- 15m height. 13-16 - relief forms derived from the complex of processes: 13 - terrace-bars with the thickness of loose deposits: a - less than 1m, b - more than 1m; 14 - dejection cone; 15 - surfaces of avalanche-mudflow genesis: a - of uncertain structure, b - represented by loose deposits of more than 3m thickness; 16-block of subsidence of bed rocks.

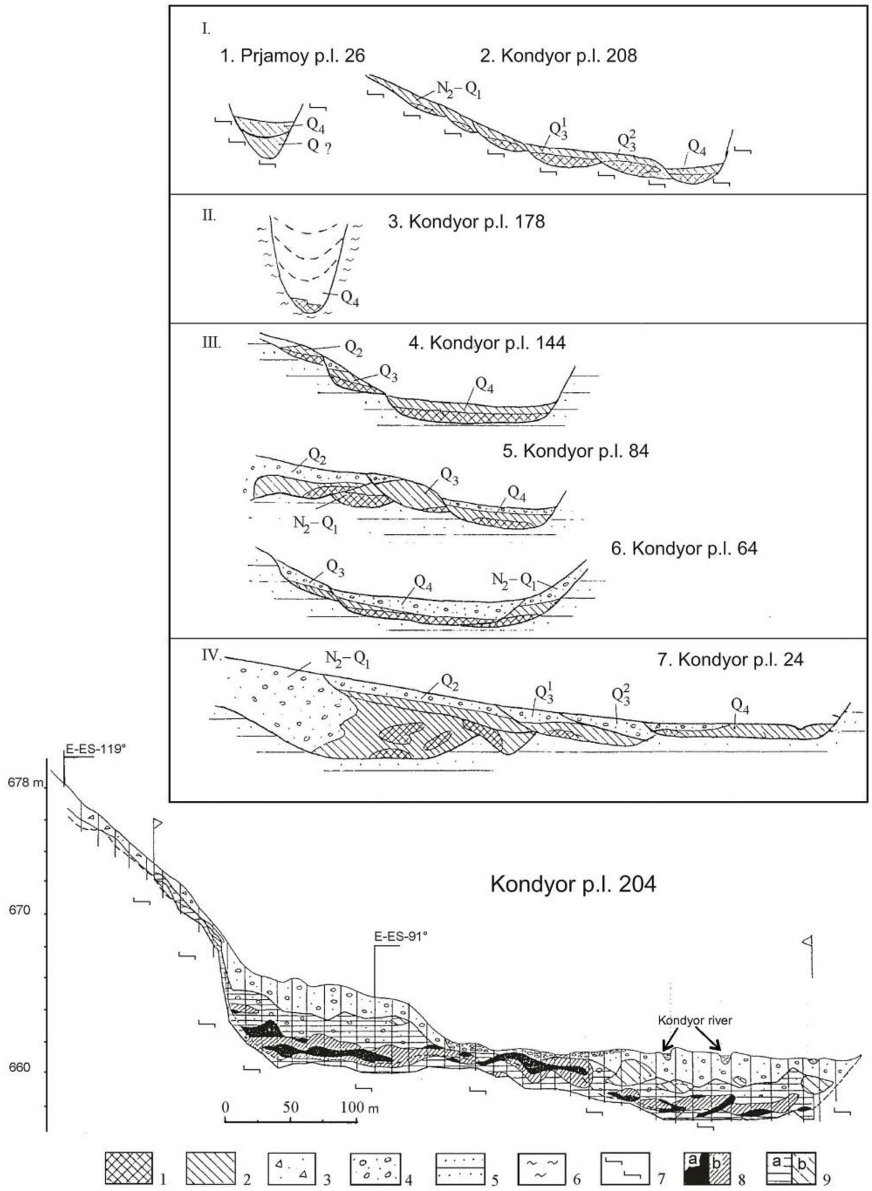

Fig. 3.3. Schematic cross sections of the valley and placer of the Kondyor river

I - inner «hollow», inside the Kondyor ring range: 1 - ravine placers, 2 - terrace and fluvial placers.

II - canyon inside the Kondyor ring range: 3 - fluvial placers on the «brush-like» bedrock /subterrane.

Ill - outside the Kondyor ring range: 4-5 - terrace-bar and valley placers in the valley with predominantly horizontal shift, 6 - valley placer in the planimorphous widening valley with the matched downcuttings.

IV - The Kondyor and Uorgalan river interfluve: 7 - valley placer and complex of buried placers at the basement of the aggradation terracebar.

Geological section of the Kondyor platinum metal placer along prospecting line 204 (from data of the Ayano-Maya GPE (Geol. Prosp. Expedition)).

1 - the Kondyor river platinum metal placer, 2 - noncommercial contents of «schlich PGM».

3 - Holocenic proluvium-solifluction deposits. 4 - Cenozoic alluvial boulder-sand-pebble deposits. 5 - Middle Riphean aleurolites and sandstones. 6 - Early Archaean metamorphic rocks. 7 - ultrabasic rocks of the Kondyor complex. 8-9 - platinum metal placer, «schlich PGM» contents: 8a - «schlich PGM», 8b - high, 9a - medium, 9b - weight contents are lower than average ones. (p.1. - prospecting line).

located outside the ring range (lower, than prospecting line 160), where medium- and fine-grained fractions become of a great importance (Table 3.2). The productivity of metal-bearing sands there is equal to the average for the placer contents. The sands of the lower site are represented by fine-grained fractions (-0.1 mm), that com¬pose 14.5 percent.

The least persistent sizing of the «schlich PGM» is seen within the bedrock source or alkaline-ultramafic massif down to prospecting line 160, where the Kondyor river cuts the ring range. From this line downstream Kondyor river and thereafter Uorgalan river particle sizes become more stable and the relative percentage of fine fractions increases sequentially. The coarse-grained fractions and nuggets are characterized by the least homogeneous distribution (Table 3.2), that is restricted to the area occupied by the placer within the «Kondyor hollow» as far as the brush-like river-bed (Kondyor river, line 160). On the «brush» itself, in the range of lines 176-164 nuggets were found even during the stage of prospecting, when a tray sampling of the sectional granodiorite rock floor was carried out. One of those nuggets, named «Birthday», weighed 73 g (see photo of the programm). Before 1997, in the course of the placer exploitation, a number of nuggets had been found (Table 3.3). The weight of the largest of them was as much as 3.5 and 5.5 kg. The bedrock «brush» within a canyon-like outlet (zone 3, Fig. 3.2. and 3.3.) was a natural barrier to prevent the removal of coarse-grained fractions of «schlich PGM» beyond the «Kondyor hollow».

Table 3.3. The abundance of the «schlich PGM» nuggets of the Kondyor placer

Weight, g	Content, wt %
5-10	55.96
10 - 15	20.62
15 - 20	9.16
20 - 25	4.32
25-30	2.63
30 - 35	1.49
35 - 40	1.46
40 - 45	0.55
45 - 50	0.39
50 - 75	1.65
75 - 100	0.84
100 - 150	0.29
150 - 200	0.13
200 - 500	0.45
500 - 1000	0.06

Note. The table is prepared on the basis of the data obtained during the placer exploitation in 1989.

The «schlich PGM» of the placer consists mainly of aggregates of minerals PGE and their fragments. Individual and twin crystals of isoferroplatinum (see photo of the programm), very rare sperrylite, laurite and iridosmine constitute only minor its amount (the first tens of mass percent). The isoferroplatinum crystals range in size from 0.2 to 30 mm. Crystals of laurite-erlicmanite and sperrylite measure from 0.1 to 5 mm.

The variation of volume weight of «schlich PGM» grains and nuggets (Table 3.4.) has showed that for the most part they contain more or less lighter non-platinum minerals (silicates, oxides, sulphides), or either pores or gas vacuoles (Fig. 3.4.). The last ones are especially common in pseudomorphs of PGM (Fig. 3.4.c,d). Visually the grains of size up to 0.1 mm seems to be monomineral and those larger than 1.0 mm represent aggregates with oxides and silicates (Fig. 3.1.). Proportions of oxide and silicate inclusions in the grains of medium sizes (Tables 3.2. and 3.4.) are approximately equal, while for the grains of coarse-sized classes and nuggets chrome-spinels prevail. Roundness of the grains and nuggets of «heavy concentrate platinum» varies from non-rounded forms to ideal ones. Such abraded grains of isoferroplatinum represent as a whole the «schlich PGM» of the lower parts of Kondyor and Uorgalan rivers. The supply of the young alluvium by the useful mineral components proceeded from the reworking of the more ancient unconsolidated deposits (zone 7, Fig. 3.2.).

Table 3.4. Average and volumetric weight of «schlich PGM» grains and contents of inclusions of silicates, oxides and other minerals in them

Fraction, mm	Average weight, mg	Volumetric average weight, g/cm^3	Content of inclusions, wt %
- 0,25	0,16	18,2	0,1
0,25 - 0,5	0,62	17,9	0,5
0,5 - 1,0	2,66	17,5	1,3
1,0 - 2,0	10,8	16,9	2,2
2,0 - 3,0	52,8	14,9	6,7
3,0 - 5,0	192,4	13,8	10,1
5,0 - 10,0	1375,3	12,1	17,3
nuggets			
5 - 100 g	14512,7	9,8	24,4
>100 g	242500,0	9,3	27,2

Note. The parameter measurements of nuggets were carried out by the example of 162 samples. The parameter measurements of grains of the «schlich PGM» were made in 5-15 specimens of 10-50 g each of them. The inclusion (oxides and silicates) weight in the samples has been calculated from the volumetric weight of the latters and relative abundance of inclusions, detected during mineralogical study

The «schlich PGM» of the Kondyor placer has its own platinum specialization at the expense of the primary role of isoferroplatinum, all the rest minerals of minor importance and rare ones are concentrated as inclusions inside its grains (Table 3.1.). The abundance of the isoferroplatinum varies in the range of 93-99 mass percent (Table 3.5.). Among the inclusions, cubic and hexagonal solid solutions of iridium and osmium (Fig. 3.4. a,b) that concentrate more than 1 mass percent of these metals are of practical importance. The weighted average of PGE chalcogenides in the «schlich PGM» is insignificant (less than 1 mass percent) (Table 3.5).

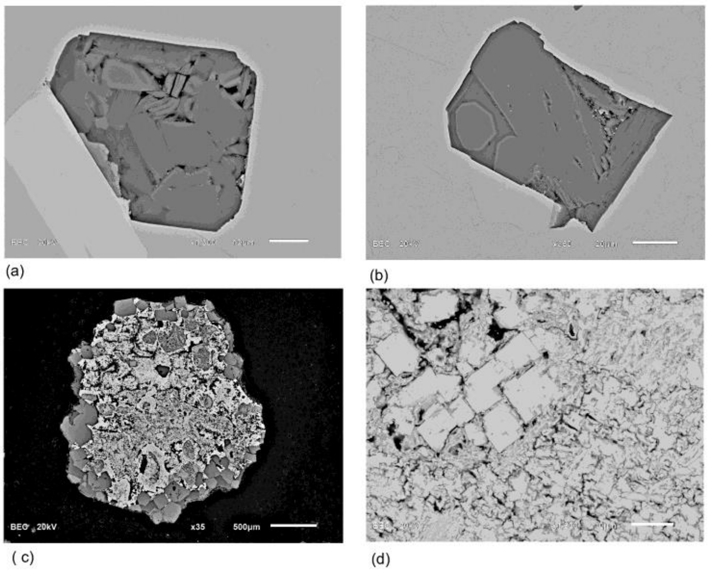

Fig. 3.4. Inclusions of silicates, oxides and gas «vacuoles» in PGM [Dmitrenko, Mochalov, 1989; Ukhanov et al., 1997]
a,b – negative cubic inclusions of intergrowth of clinopyroxene, amphibole, phlogopite, chlorite, apatite with gas «vacuoles» in isoferroplatinum with (light-grey): a – native osmium, b – native iridium; c,d – pseudomorphs of PGM with gas «vacuoles»: c – on early PGM in aggregates with chromespinelides (grey), d – with newly formed cubic crystals of isoferroplatinum (light)

Table 3.5. Average chemical composition and phase composition of «schlich PGM» of the placer deposit of platinum group metals Kondyor (based on mineralogical study)

№	Watercourse	Minerals	Elements, wt %												Phase contentwt, %
			Pt	Ir	Os	Ru	Rh	Pd	Cu	Ni	Fe	S	As		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Pryamoy	1	82,69	2,72	1,09	0,17	0,63	0,37	0,67	0,16	9,09	0,12	0,07	2,21	
		2	82,52	2,06	0,30	0,10	0,58	0,36	0,66	0,16	9,07	-	-	-	95,81
		3	0,08	0,45	0,25	0,02	0,01	<0,01	<0,01	<0,01	0,01	-	-	-	0,83
		4	0,01	0,07	0,46	0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,56
		5	0,08	0,14	0,08	0,04	0,04	0,01	0,01	0,01	0,01	0,12	0,07	-	0,59
		6	4–2=1,18; 2–1=1,18; 1–0,5=0,38; 0,5–0,25=0,12											2,21	2,21
2	Anomalniy	1	81,99	3,52	1,93	0,29	0,54	0,36	0,72	0,07	8,11	0,40	0,05	2,02	
		2	81,66	1,86	0,18	0,05	0,44	0,36	0,67	0,07	8,09	-	-	-	93,38
		3	0,19	1,13	0,46	0,06	0,02	<0,01	<0,01	<0,01	0,01	-	-	-	1,87
		4	0,02	0,24	0,97	0,01	<0,01	<0,01	<0,01	-	<0,01	-	-	-	11,25
		5	0,12	0,29	0,32	0,17	0,08	<0,01	0,05	<0,01	0,01	0,40	0,05	-	1,49
		6	10–5=0,29; 5–3=0,30; 3–2=0,27; 2–1=0,67; 1–0,5=0,4; 0,5–0,25=0,15											2,02	2,02
3	Trezubets	1	83,55	2,30	1,55	0,09	0,43	0,30	0,49	0,13	8,53	0,19	0,11	2,29	
		2	83,29	1,60	0,44	0,03	0,38	0,28	0,47	0,13	8,52	-	-	-	95,15
		3	0,07	0,34	0,19	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,64
		4	0,01	0,11	0,78	0,01	<0,01	-	<0,01	-	<0,01	-	-	-	0,92
		5	0,18	0,25	0,14	0,04	0,04	0,02	0,02	-	0,01	0,19	0,11	-	1,00
		6	10–5=0,34; 5–3=0,51; 3–2=0,24; 2–1=0,70; 1–0,5=0,38; 0,5–0,25=0,12											2,29	2,29
4	Uzniy	1	83,82	2,24	0,79	0,14	0,69	0,26	0,78	0,16	9,22	0,05	0,07	1,73	
		2	83,73	2,00	0,19	0,12	0,67	0,26	0,78	0,16	9,22	-	-	-	97,14
		3	0,02	0,12	0,06	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,23
		4	<0,01	0,07	0,42	0,01	<0,01	-	-	<0,01	<0,01	-	-	-	0,51
		5	0,07	0,05	0,12	0,01	0,02	<0,01	<0,01	<0,01	<0,01	0,05	0,07	-	0,39
		6	10–5=0,24; 5–3=0,22; 3–2=0,18; 2–1=0,57; 1–0,5=0,33; 0,5–0,25=0,19											1,73	1,73

Table 3.5. continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5	Begyn	1	80,55	2,99	1,51	0,19	0,73	0,43	0,69	0,18	9,36	0,06	0,03	3,27	
		2	80,41	2,30	0,31	0,12	0,70	0,43	0,68	0,18	9,34	-	-	-	94,48
		3	0,10	0,49	0,31	0,02	0,01	<0,01	<0,01	<0,01	0,01	-	-	-	0,94
		4	0,02	0,14	0,86	0,02	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	1,04
		5	0,02	0,06	0,03	0,03	0,02	<0,01	0,01	<0,01	0,01	0,06	0,03	-	0,27
		6	10–5=1,48; 5–3=0,44; 3–2=0,27; 2–1=0,65; 1–0,5=0,30; 0,5–0,25=0,12											3,27	3,27
6	Maliy	1	83,18	2,12	1,14	0,18	0,48	0,49	0,69	0,18	8,43	0,14	0,08	2,84	
		2	83,01	1,50	0,17	0,11	0,42	0,48	0,68	0,18	8,43	-	-	-	94,99
		3	0,07	0,36	0,20	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,66
		4	0,01	0,11	0,68	0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,83
		5	0,09	0,15	0,09	0,05	0,05	0,01	0,01	<0,01	0,01	0,14	0,08	-	0,68
		6	4–2=1,64; 2–1=0,81; 1–0,5=0,33; 0,5–0,25=0,06											2,84	2,84
7	Korotish	1	80,71	3,68	2,44	0,28	0,70	0,36	0,67	0,15	8,39	0,24	0,08	2,25	
		2	80,35	2,29	0,28	0,09	0,58	0,36	0,64	0,15	8,38	-	-	-	93,15
		3	0,18	0,82	0,48	0,04	0,02	<0,01	<0,01	<0,01	0,01	-	-	-	1,55
		4	0,04	0,38	1,54	0,05	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	2,03
		5	0,14	0,19	0,14	0,10	0,09	<0,01	0,03	<0,01	0,01	0,24	0,08	-	
		6	4–2=1,07; 2–1=0,66; 1–0,5=0,43; 0,5–0,25=0,09											2,25	1,02
8	Appendix	1	80,96	3,16	1,5	0,21	0,50	0,35	0,68	0,18	8,70	0,14	0,11	3,48	
		2	80,50	2,02	0,22	0,09	0,45	0,32	0,67	0,18	8,70	-	-	-	93,16
		3	0,17	0,78	0,36	0,07	0,02	<0,01	<0,01	<0,01	0,01	-	-	-	1,43
		4	<0,01	0,26	0,76	0,03	<0,01	<0,01	<0,01	-	-	-	-	-	1,04
		5	0,29	0,1	0,16	0,02	0,03	0,02	0,01	<0,01	<0,01	0,14	0,11	-	0,89
		6	4–2=2,47; 2–1=0,69; 1–0,5=0,28; 0,5–0,25=0,04											3,48	3,48
9	Creek headwaters of Kondyor river	1	82,08	2,71	1,34	0,16	0,63	0,37	0,66		9,01	0,12	0,07	2,66	
		2	81,91	2,04	0,30	0,10	0,58	0,36	0,65	0,16	9,0	-	-	-	95,10
		3	0,08	0,41	0,23	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,75
		4	0,01	0,12	0,73	0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,89
		5	0,08	0,14	0,08	0,04	0,04	0,01	0,01	<0,01	0,01	0,12	0,07	-	0,60
		6	10–5=0,89; 5–3=0,41; 3–2=0,26; 2–1=0,65; 1–0,5=0,32; 0,5–0,25=0,13											2,66	2,66

Table 3.5. continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10	Kondyor, p.l. 212	1	84,69	2,28	0,61	0,13	0,63	0,35	0,64	0,14	8,78	0,12	0,09	1,52	
		2	84,52	1,85	0,21	0,07	0,57	0,35	0,63	0,13	8,78	-	-	-	97,13
		3	0,05	0,22	0,10	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,38
		4	<0,01	0,05	0,22	0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,29
		5	0,12	0,16	0,08	0,04	0,05	<0,01	0,01	0,01	0,01	0,12	0,09	-	0,68
		6	4–2=0,24; 2–1=0,67; 1–0,5=0,49; 0,5–0,25=0,12											1,52	1,52
11	Kondyor, p.l. 204	1	83,93	2,07	1,28	0,12	0,51	0,37	0,73	0,10	8,58	0,09	0,11	2,09	
		2	83,68	1,36	0,17	0,07	0,47	0,37	0,72	0,10	8,58	-	-	-	95,52
		3	0,12	0,47	0,23	0,01	0,01	-	<0,01	-	0,01	-	-	-	0,85
		4	<0,01	0,11	0,81	0,01	<0,01	<0,01	<0,01	-	<0,01	-	-	-	0,94
		5	0,13	0,13	0,07	0,03	0,03	<0,01	0,01	<0,01	<0,01	0,09	0,11	-	0,60
		6	10–5=0,32; 5–3=0,23; 3–2=0,36; 2–1=0,69; 1–0,5=0,37; 0,5–0,25=0,12											2,09	2,09
12	Kondyor, p.l. 192	1	83,87	2,30	0,90	0,11	0,61	0,35	0,63	0,12	8,70	0,06	0,05	2,25	
		2	83,75	1,83	0,21	0,07	0,57	0,35	0,62	0,12	8,70	-	-	-	96,23
		3	0,05	0,26	0,12	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,47
		4	<0,01	0,12	0,53	0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,68
		5	0,07	0,09	0,04	0,02	0,03	<0,01	0,01	<0,01	0,01	0,06	0,05	-	0,37
		6	10–5=0,36; 5–3=0,25; 3–2=0,43; 2–1=0,75; 1–0,5=0,35; 0,5–0,25=0,11											2,25	2,25
13	Kondyor, p.l. 176	1	83,75	2,72	0,71	0,09	0,69	0,32	0,56	0,14	8,79	0,06	0,02	2,13	
		2	83,65	2,22	0,25	0,06	0,65	0,32	0,55	0,14	8,78	-	-	-	96,61
		3	0,06	0,35	0,16	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,60
		4	<0,01	0,07	0,27	0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,36
		5	0,04	0,08	0,03	0,01	0,03	<0,01	0,01	<0,01	0,01	0,06	0,02	-	0,30
		6	4–2=0,88; 2–1=0,71; 1–0,5=0,46; 0,5–0,25=0,08												
14	Kondyor, p.l. 216-160	1	84,10	2,41	0,87	0,12	0,62	0,35	0,63	0,12	8,72	0,09	0,06	1,9	
		2	83,95	1,85	0,21	0,07	0,57	0,35	0,062	0,12	8,72	-	-	-	96,46
		3	0,06	0,34	0,16	0,01	0,01	0,01	0,01	0,01	0,01	-	-	-	0,58
		4	0,01	0,10	0,45	0,01	0,01	0,01	0,01	0,01	0,01	-	-	-	0,57
		5	0,09	0,12	0,05	0,03	0,04	0,01	0,01	0,01	0,01	0,09	0,06	-	0,49
		6	10–5=0,26; 5–3=0,18; 3–2=0,30; 2–1=0,65; 1–0,5=0,36; 0,5–0,25=0,15											1,9	1,9

Table 3.5. continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
15	Kondyor, p.l. 216-160 and creeks	1	83.52	2.50	1.00	0.13	0.62	0.36	0.64	0.13	8.80	0.10	0.07	2.11	
		2	83.35	1.91	0.24	0.08	0.57	0.35	0.63	0.13	8.79	-	-	-	96.05
		3	0.07	0.35	0.17	0.01	0.01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.62
		4	0.01	0.11	0.52	0.01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.66
		5	0.09	0.13	0.07	0.03	0.04	0.01	0.01	<0,01	0.01	0.10	0.07	-	0.56
		6	10–5=0,44; 5–3=0,24; 3–2=0,29; 2–1=0,65; 1–0,5=0,35; 0,5–0,25=0,14											2.11	2.11
16	Kondyor, p.l. 136	1	85.07	1.55	0.58	0.09	0.48	0.42	0.71	0.13	8.60	0.02	0.01	2.28	
		2	85.01	1.32	0.20	0.06	0.47	0.42	0.71	0.13	8.60	-	-	-	96.92
		3	0.04	0.16	0.07	0.01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.28
		4	0.01	0.05	0.32	0.01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.40
		5	0.01	0.02	0.03	0.01	0.01	<0,01	<0,01	<0,01	<0,01	0.02	0.01	-	0.12
		6	4–2=1,44; 2–1=0,25; 1–0,5=0,45; 0,5–0,25=0,14											2.28	2.28
17	Kondyor, p.l. 128	1	86.49	1.35	0.55	0.10	0.48	0.45	0.69	0.15	8.90	0.04	0.01	0.77	
		2	86.43	1.10	0.19	0.06	0.47	0.45	0.69	0.15	8.90	-	-	-	98.45
		3	0.04	0.18	0.07	0.01	0.01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.30
		4	0.01	0.05	0.24	0.01	<0,01	-	<0,01	<0,01	<0,01	-	-	-	0.32
		5	0.01	0.02	0.05	0.02	0.01	<0,01	<0,01	<0,01	<0,01	0.04	0.01	-	0.16
		6	4–2=0,05; 2–1=0,12; 1–0,5=0,34; 0,5–0,25=0,24; –0,25=0,01											0.77	0.77
18	Kondyor, p.l. 108	1	85.96	1.93	0.59	0.05	0.47	0.33	0.68	0.12	8.64	0.02	0.02	1.17	
		2	85.88	1.43	0.11	0.03	0.46	0.33	0.68	0.12	8.63	-	-	-	97.66
		3	0.07	0.43	0.19	0.01	0.01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.73
		4	<0,01	0.04	0.27	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.32
		5	0.01	0.03	0.02	0.01	0.01	<0,01	<0,01	<0,01	<0,01	0.02	0.02	-	0.12
		6	4–2=0,23; 2–1=0,19; 1–0,5=0,51; 0,5–0,25=0,23; –0,25=0,01											1.17	1.17
19	Kondyor, p.l. 80	1	86.06	1.98	0.60	0.09	0.58	0.46	0.70	0.16	8.77	0.02	0.02	0.57	
		2	86.00	1.71	0.12	0.06	0.56	0.46	0.70	0.14	8.77	-	-	-	98.53
		3	0.04	0.19	0.08	0.01	0.01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.34
		4	0.01	0.06	0.38	0.01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.46
		5	0.01	0.02	0.02	0.01	0.01	<0,01	<0,01	<0,01	<0,01	0.02	0.02	-	0.11
		6	2–1=0,04; 1–0,5=0,22; 0,5–0,25=0,29; –0,25=0,02											0.57	0.57

Table 3.5. continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
21	Kondyor, p.l. 32	1	86.57	1.32	0.54	0.06	0.49	0.45	0.79	0.15	8.89	0.02	0.02	0.65	
		2	86.54	1.11	0.22	0.05	0.48	0.45	0.79	0.15	8.89	-	-	-	98.69
		3	0.02	0.14	0.06	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.24
		4	<0,01	0.04	0.24	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.30
		5	0.01	0.03	0.02	0.01	0.01	<0,01	<0,01	<0,01	<0,01	0.02	0.02	-	0.12
		6	2–1=0,15; 1–0,5=0,20; 0,5–0,25=0,27; –0,25=0,03											0.65	0.65
22	Kondyor, p.l. 160-16	1	85.88	1.65	0.63	0.09	0.49	0.42	0.71	0.13	8.68	0.03	0.01	1.28	
		2	85.82	1.33	0.21	0.06	0.47	0.42	0.71	0.13	8.68	-	-	-	97.83
		3	0.04	0.24	0.11	0.01	0.01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.41
		4	0.01	0.05	0.28	0.01	<0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0.35
		5	0.01	0.03	0.03	0.01	0.01	<0,01	<0,01	<0,01	<0,01	0.03	0.01	-	0.13
		6	4–2=0,26; 2–1=0,46; 1–0,5=0,38; 0,5–0,25=0,17; –0,25=0,01											1.28	1.28
23	Uorgalan, p.l. 24	1	86,54	1,35	0,49	0,10	0,91	0,44	0,79	0,17	8,69	0,02	0,01	0,49	
		2	86,48	1,07	0,14	0,06	0,89	0,44	0,79	0,17	8,69	-	-	-	98,73
		3	0,04	0,20	0,09	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,35
		4	0,01	0,04	0,22	0,01	0,01	<0,01	<0,01	<0,01	<0,01	-	-	-	0,27
		5	0,02	0,04	0,04	0,02	0,01	<0,01	<0,01	<0,01	<0,01	0,02	0,01	-	0,16
		6	1-0,5=0,16; 0,5-0,25=0,30; -0,25=0,03											0,49	0,49
24	Kondyor, p.l. 216-160 and Uorgalan creeks, p.l. 180-24	1	84,84	2,03	0,77	0,12	0,54	0,39	0,69	0,13	8,73	0,06	0,04	1,62	
		2	84,74	1,59	0,21	0,07	0,51	0,39	0,68	0,13	8,73	-	-	-	97,05
			0,06	0,30	0,13	0,01	0,01	0,01	0,01	0,01	0,01	-	-	-	0,52
			0,01	0,07	0,37	0,01	0,01	0,01	0,01	0,01	0,01	-	-	-	0,48
			0,03	0,07	0,06	0,03	0,02	0,01	0,01	0,01	0,01	0,06	0,04	-	0,32
			4-2=0,55; 2-1=0,53; 1-0,5=0,39; 0,5-0,25=0,14; -0,25=0,01											1,62	1,62

Note. Composition is calculated by the original programs based on the results of sieve and mineralogical analyze of 406 exploration and 30 operational samples of «schlich PGM»; 248 determinations of volume weight and study of 5723 polished sections of isoferroplatinum; 1280 microprobe measurements of full chemical composition of PGM. 1 – «schlich PGM»; 2 – isoferroplatinum; 3 – cubic solid solutions of Ir, Os and Pt; 4 – hexagonal solid solutions of Os, Ru and Ir; 5- sulfides and arsenides PGE; 6 – silicates, oxides and other minerals. 10-5; 5-3; 3-2; 2-1; 1-0,5; 0,5-0,25 fraction of «schlich PGM» in mm. p.l. – prospecting line

Isoferroplatinum is characterized by the constant composition of major mineral-forming elements of platinum and ferrum that approximates the stoichiometry. Variations of the trace element contents can be seen simultaneously. The distribution of iridium in the ferroplatmum is the most distinctive. It is characterized by the following lognormal types: 1 - poor in iridium (Ir < 0.5 mas.%); 2 -average iridium content; 3 - high iridium content (Ir > 2.5 mas.%) [Geology…, 1994, Mochalov et al., 1998, 2007] .

Research of «schlich PGM» from the alluvial placers of the lst-5th order channels of the Kondyor-Uorgalan river basin had assigned that its mineral and chemical compositions are reasonably of the same type (Table 3.5). At the same time relative changeability of iridium, osmium and rutenium contents, as well as inconstancy of amounts of its phases (Tables 1 and 5), are observed. It is especially pronounced near the channels, occurring in endogenous contacts of the dunite with koswite of the Aldan complex (see the map), for instance, in the brook Anomalny. Taking into consideration that the «schlich PGM» from alluvium of the 1 st-5th order channels accounts for the mineralogy of the alluvium formation of different age cycles, it is clear that the revealed relative variations of PGE mineral composition correspond to its proportions in the section of the bedrock source. The most part of the reserves of the Kondyor river placer is represented by the «schlich PGM» with an intermediate iridium content (Table 3.5) and its greatest abundance is connected with the alluvium of the earlier periods of erosion and accumulation that had formed the valleys. The fact seems to be proof of the suggestion that the placer-forming segregation of the middle-iridium isoferroplatinum had predominantly crystallized in a roof of the concentrically zoned alkaline-ultramafic massif Kondyor [Mochalov, 1997; 2005].

Table 3.6. Magnetic properties of the «schlich PGM» of the Konder placer.

№	Location	T_c(K)	Specific magnetization (per gram)				M_{sh}/Ms_o	Mr_{sh}/Mr_{so}	M $_{fer.}$%
			Ms_o	M_{sh}	M_{rso}	M_{rsh}			
1	trib. Raspadok	420	7740	5400	1070	336	0,70	0,29	55
2	trib. Maliy, p.l. 8	420	17730	14180	4100	2880	0,80	0,73	90
3	trib. Maliy, p.l. 8	410	22140	20130	4600	3940	0,91	0,86	50
4	r.Kondyor, p.l. 176	430	60000	24240	16500	5240	0,40	0,32	93
5	r.Kondyor, p.l. 176	410	57130	32600	14700	7820	0,57	0,53	85
6	r.Kondyor, p.l. 128	390	49600	45560	12380	11180	0,92	0,90	90
7	r.Kondyor, p.l. 56	360	9546.0	14530	21050	1750	0,15	0,08	60
8.	r.Kondyor, p.l. 32	390	114900	84360	27740	19980	0,73	0,72	90

Note. Ms_o - magnetic saturation moment; M_{sh} - induced magnetic saturation moment after heating; Mrs_o - remanent magnetic saturation moment; Mrs_h - remanent induced magnetic saturation moment after heating; M_{fer} - quantity of the magnetic moment lost after heating. Magnetic properties investigations have been conducted by V.S.Pechnikov, samples of «schlich PGM» grains weigh¬ing 0.5-1.6 g. The measurements were performed with an original vibration magnetometer that permitted to determine the parameters of magnetic saturation at any temperature of a sample in the field of saturation of 2000 CE. A scale division of the magnetometer is $4.1\times10^{-9}Am^2$ (4×10^{-6} unit SGSM). The «schlich PGM» being heated up to the isoferroplatinum Curie point - T_c(K), the most part of initial magnetic and induced saturation moments is lost. The revealed feature can be used at magnetic separation of a «schlich PGM» from magnetite-bearing grains of heavy concentrates, for which purpose its mixture should be heated up to the temperature of 80-120°C that will result in practical loss of ferromagnetic properties of platinum.
p.l. – prospecting line.

Magnetic measurements of the isoferroplatinum had shown a wide range of variation of its specific magnetization (Table 3.6). The least magnetic isoferroplatinum is concentrated in ravine alluvial placers. In the valley alluvial deposits the magnetization of isoferroplatinum rises as its distance from the bedrock source in creases. Being heated up to the Curie point, isoferroplatinum loses the most part (55-90%) of its initial and induced magnetic moments of saturation. It clearly demonstrates that such a magnetization of isoferroplatinum is acquired during the placer formation.

The Kondyor placer is the alluvial deposit of platinum metals with simultaneous gold mineralization. The native gold, rather commonly accompanying the «schlich PGM», has irregular shapes of flat lumps or clots with spongy, rough surface. The golden grain sizes change from fine fractions to nuggets. For the most their part the roundness is good or medium. At times rims or incrustations of native gold cover grains of the «schlich PGM» that are distinguished for its very varied and inconstant chemical com¬position (photo of the programm). Besides Ag, other elements, such as Cu,Pd, Pt are inherent in the native gold (Table 3.1). Native gold is in syngenetic intergrowth with intermetallics of Pd and Pt (Table 3.1).

4. BRIEF GEOLOGICAL DESCRIPTION OF THE ULTRAMAFIC AND ALKALINE ROCKS OF THE CONCENTRICALLY ZONED KONDYOR MASSIF[1]

The ultramafic and alkaline rocks of the concentrically zoned Kondyor massif (57°32′ n.l., 134°38′ e.l.) are located in the Batomskiy geoblock of Aldan shield in the intersection of two deep faults: submeridional Berainskiy fault and sublatitudinal Kondyor-Netskiy fault. Concentrically zoned Kondyor massif at the modern erosion level in the plan has a form of a circle with a diameter up to 8.5 km. Massif is mainly composed by the ultramafic rocks (see the map).

In the frame of the Kondyor massif the Lower Archean metamorphic rocks and Middle Riphean sedimentary rocks are developed, corresponding respectively to the basal and plate complexes of the eastern part of the Aldan shield.

Low Archean metamorphic rocks are exposed on the area of 6 km2 in the inner overwatershed slopes of the ring-shape ridge. They contact with dunite-clinopyroxenite-kosvite-gabbro rocks of Aldanian and Kondyor complexes. These metamorphic rocks form intermittent «ring» with width from tens of meters to one km and have centerclinal dip with the strike about 60 °.

Middle Riphean rocks are presented by Kondyor and Omninskaya suites. Kondyor suite is exposed in the inner overwatershed slopes of the ring-shape ridge. It occurs with angular and stratigraphic unconformity directly on the rocks of basement. Omninskaya suite conformable overlaps the Kondyor suite and is exposed on the watershed and external slopes of Kondyor ridge. Middle Riphean terrigenous rocks occur periclinal. Their strike is changing from 50°-60° near the massif to 5° -7° at a distance of 1.5-2.0 km away. Sedimentary rocks underwent contact-thermal metamorphism. The rocks are intensively hornfelsed and as result they are dense, strong and slightly affected to weathering. In sedimentary rocks accessory minerals are presented by pyroxene, chromespinel, amphibole and in rare cases PGMs and native gold. Source of chromespinelides and PGMs were probably the ultramafic rocks of Kondyor complex (?).

Cenozoic alluvial deposits within the ring-shape ridge of Kondyor have not survive in its original form due to working out the placer of platinum metals. Currently creeks flow through the boulder-sand-and-pebble technogenic deposits with content of «schlich PGM» from 0.01 to 0.1 g/m3.

Intrusive rocks of the Kondyor massif are presented by early Archean, early Proterozoic (?), early Riphean (?) and Cretaceous formations.

Early Archean gneiss-like plagiogranites are located in southern and southern-western exocontacts of massif and form intermittent zone with the length around 5.7 km and width in plan 50-400 m. With Early Archean metamorphic rocks they form around the massif practically uninterrupted ring with the width 100-600 m.

Early Proterozoic (?) mafic-ultramafic formation relating to Kondyor dunite-clinopyroxenite complex (see the map) occupy almost the entire area of the massif. Dunite, compose the core of the massif that is about 5.5 km in diameter. Among them are distinguished fine-grained, medium-grained, coarse-grained, pegmatoid (dunite pegmatites) varieties. They have cumulative magmatic porphyritic textures, as well as recrystallized porphyroclastic textures (Burg et al. 2009).

Medium-finegrained dunites on the contact with clinopyroxenites form a continuous external ring-shape rim with width from 100 to 250 m and more. They consist of olivine (99%), chromespinelide and diopside.

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[1] *This chapter is written based on the archive and published materials of E.P. Emel'yanenko, O.N. Khomenko and coauthors (Artel «Amur») and is accompanying with the geological map «Ultramafic and alkaline rocks of the concentrically zoned Kondyor massif» that was also created by the Artel «Amur».*

Medium-finegrained, porphyritic and porphyroclastic differences occupy the interior part of the dunite core. They are composed of olivine (95-99%), chromospinelide (1-5%) and accessory minerals (titanomagnetite, ilmenite, Fe and Ni sulfides and PGM). In the large olivine megacrysts the microinclusions of magnetite, chrome-magnetite and clinopyroxene are observed. Chromespinelides are divided into: (1) accessory (dispersed segregations with size from 0.01 to 4 mm); (2) the segregation-schlieren (from the first cm to tens of centimeters); (3) irregularly-lenticular vein (length up to several meters). The richest occurrences of PGM are associated with chromitite.

Dunite-pegmatites form bodies with polygonal textures and the irregular shape (with the size up to hundreds of m^2), and vein-like bodies with length up to 700 m and width up to 50 m. Most part of the dunite-pegmatites is localized within the zone of 1.5 km around biotite-clinopyroxenite metasomatites. Dunite-pegmatites consist of olivine (90-92%), chromespinelide (1-6%), titanomagnetite (1-5%), and clinopyroxene (1-3%). Microinclusions of magnetite and chromemagnetite are presented in the olivine. Size of the crystals of olivine is from 0,5 to 7 cm. Sometimes olivine megacrysts form a shliere-like segregations in medium-finegrained dunites especially in the endo- and exocontact zones of some dunite-pegmatite bodies.

The late phase of Kondyor complex is presented by clinopyroxenites. They form around the dunite core a ring-shape body with width 50-570 m. Pyroxenites consist from diopside (99%) and accessory minerals – olivine, chromespinelide, titanomagnetite, ilmenite (around 1%). The size of pyroxene grains varies from first mm in the near contact zone to several cm in the central part of the body. The contact of finegrained dunites with clinopyroxenites usually traces the ring periclinal fault. Often near the contact the olivine-diopside metasomtites are observed. Sometimes magmatogenic werhlites are found between dunites and pyroxenites.

Contacts of clinopyroxenites with Archean host-rocks are rarely observed. Usually contacts are presented by kosvites and potassium-feldspar-clinopyroxenite metasomatic rocks. In the clinopyroxenites the xenolithes of the scarned marbles are found.

In the western exocontact of Kondyor ultramafic rocks the Early Riphean (?) granitic formations are presented by the dykes and dyke-like bodies of subalkaline pegmatoid granites. Also some of dykes of subalkaline leucocratic finegrained granites and some of dykes of graphic and pegmatoid granites cut Early Archean plagiogranites and Earle Proterozoic (?) clinopyroxenites.

Aldanian late Mesozoic complex consist from 3 groups of magmatic rocks: volcanogenic, monzonitic and alkaline ones. Different contact metamorfic rocks and metasomatites were also formed during the late Mesosoic magmatic event (see the map).

Early Mesozoic subvolcanogenic rocks are presented by the sills and dykes of trachyandesites, granodiorite-porphyrite and rhiolites.

Monzonitic group consist from rocks of two phases. The first phase is presented by kosvites, gabbro and hornblendites. Kosvites and gabbro on the outer part of the rim form arc-like bodies with the length up to 6 km and width up to 0,4 km. Kosvites usually are localized closer to the center of the massif. Large intrusion in the central-western part of the dunite “core” and differently orientated dykes in ultramafic rocks of Kondyor complex are also presented by kosvites. The roof of the kosvite intrusion is uncovered by the borehole #1 on the depth of 288 m. Contact of kosvites with dunites and clinopyroxenites are sharp and intrusive. Dykes of kosvites streach for 1-10 m with width from 0,01 to 2 m.

Gabbro is usually observed between clinopyroxenites and rocks of the basement. Content of plagioclase in the gabbro increases with distance from clinopyroxenites. On the contrary, content of augite and titanomagnetite is decreasing. At the places where clinopyroxenites are separated from gabbro by kosvites gradual transformation can be observed. Kosvites change to gabbro through plagioclase-bearing kosvites and melanocratic gabbro.

Hornblendites are presented by the thick dykes of significantly amphibole rocks with clinopyroxene, titanomagnetite and titanite.

The rocks of the second montozonitic group are presented by bodies and dykes of subalkaline quartz diorites and quartz monzodiorites, subalkaline diorites, as well as by dykes of alkaline-potassium-feldspar syenites. They are observed on the northern-eastern part of the massif among metamorphic rocks, gabbro and pyroxenites. Dykes of alkaline-pottasium-feldspar syenites are found in exo- and endocontact zones of dunite stock.

Rocks of alkaline group are presented by dykes of alkaline and feldspar-syenites and their pegmatites, as well as by the alkaline granites. Alkaline syenites and its pegmatites are divided on (1) augerine, augerine-arfedsonite, apatite-arfedsonite syenites; (2) melanite syenites. Rocks of the first group are observed mainly in the central part of dunite "core" as heavy pitching (60-90°) veins and dykes with thickness from 5 cm to 2 m. Melanite syenites form single dykes mainly among diorite porphirites.

Feldspar-syenites are divided: 1) lujaurite and its pegmatites; 2) cancrinite lujaurite; 3)miascite and miascite-lujaurite; 4) pectolite lujaurite. Mainly lujaurites are observed on the periphery of dunite "core" and in pyroxenites. Zoned dykes of lujaurites (thickness 1-8 m) dip from the center with angles 40-80°.

Alkaline granites are presented by single dykes with thickness of 0,2-0,5 m among melanocratic gabbro and gneiss-like plagiogranites in the southern-eastern part of the massif.

Intrusion of montzonitic and alkaline groups of Aldanian complex were accompanied with singnificant metasomatic and contact alteration on the host-rocks.

Metasomatites of apatite-titanomagnetite-biotite-amphibole-clinopyroxene composition are the most common. They are presented by the veins with thickness from several centimeters to several meters that stretches for hundred of meters. They are observed practically over the whole volume of dunites. In the western part of dunite body metasomatites form complex zone of "stockwork" with the size 2-3 km^2. These metasomatites are formed around the contact of large intrusion of kosvites.

Olivine-diopside metasomatites in the contact zone of finegrained dunites with pyroxenites form practically closed ring with width from 10 cm to 200 m. These metasomatites are composed by chromediopside and olivine (15-20%) and rare titanomagnetite. Olivine-diopside metasomatites are also observed around the dykes of alkaline syinetes and kosvites in dunites.

Around the massif magnesial and lime skarns are developed: garnet-diopside, spinel-monticellite, forsterite, garnet-vesuvianite, amphibol-magnetite. Their compositions are highly variable. They are formed due to the formation of monzonitic group.

Feldspar-clinopyroxene metasomatites (near skarn) are developed on mafic metamorphic rocks. Mainly they are spread in the western part of the massif. They stretch for 3 km with the width up to 250 m.

Amphibole-serpentine and sungulite-vermiculite-montmorillonite metasomatites are widely spread. They are found in dunites as single viens of greenish-white color with thickness from first mm to tens of centimetrs. Sometimes these veins form swarm up to 10-50 m. Mainly they are formed in the fractured zones in the rocks of monzonitic and alkaline group.

Based on petrochemistry (content of Na_2O, K_2O and SiO_2) dunites, clinopyroxenites and kosvites can be classified as low-alkaline ultramafic rocks. Thus there is a similarity with platinum-bearing gabbro-pyroxenite-dunite cumulative complexes of Urals and Alaska. At the same time rocks of monzonitic and alkaline group are petrochemical classified as moderately-alkaline and alkaline and refers Kondyor massif to alkaline-ultramafic formation.

High concentration (above clarke) of PGE on the Kondyor massif is mainly associated with four types of rocks:

1) Segregations and veinlets of chromespinelides in dunites;
2) Veins of clinopyroxenite metasomatites;
3) Sulfidized gabbro;
4) Titanomagnetite-clinopyroxenite and titanomagnetite-clinopyroxenite-phlogopite metasomatites with copper specialization.

1 type. Dunites. As a result of prospecting works within dunite massif Kondyor and his frame more than 200 small ore occurrence of PGE was found. They are divided into three main types.

1. Dunite with accessory chromite, which do not differ from the surrounding dunite. Platinum content of ore occurrences is in the range of 1-3 g/t.

2. Segregation of chromespinellides with size from 3-5 cm to 0.8-10.5 m (average 5-20 cm). Platinum content in them is usually in the range of 1-3 g/t, but sometimes reaches 10-80 g/t, and in rare cases up to 200 g/t.

3. Large segregations of chromespinellides that usually have an elongated shape with a width to length ratio of 1:2 to 1:10, and obscure boundaries with the surrounding dunites. Most segregation of chromespinellides and small (up to 3 meters) intervals of dunite with no visible segregation have industrial content of Pt metal. Platinum is generally dusty, but sometimes it forms aggregates up to 5 mm. A typical example is on the left border of creek Malyi. Small ore occurrence “Verkhnee”, which in terms of size is 30×15 m, have estimated resources (P1 category) about 100 kg with an average grade of platinum 29.5 g/t.

2 type. Vein-like bodies of clinopyroxenites, clinopyroxene-phlogopite and clinopyroxene-feldspar metasomatites that have up to 1% of accessory titanomagnetite, ilmenite and chromespinellide. With these rocks sulphide (mainly chalcopyrite) and Pt-mineralization is associated. Pt and Pd content in them is in the range respectively of 0.1 g/t and 0.6 g/t. Rarely Pt-metal content is up to the first g/t.

3 type. Gabbro with dispersed accessory impregnations of Cu and Fe sulfides. Several geochemical aureoles with Pt and Pd content up to few tenths of g/t are observed.

4 type. Vein-like kosvites and apatite-titanomagnetite-biotite-amphibole-clinopyroxene metasomatites with Cu specialization and with various ratios of pyroxene, phlogopite (vermiculite), titanomagnetite, feldspar, apatite. Pt and Pd are associated with the copper mineralization, their content is up to the first g/t in individual samples.

1: 25 000

there are 250 meters in 1 centimeter

m 1000 750 500 250 0 1 km

Prepared by E. Emelyanenko

Legend to the geological map of pre-Neogene formations scale 1:25000

Geochronological scale: period, epoch, century, time

cretaceous – early

proterozoic – later – riphean – middle; early

proterozoic – early

archaean – early

Early cretaceous magmatic and metasomatic formations

Maisky suite, Omninsky suite

Upper subsuite - black aleurolites, argillites, rarely fine-grained sandstone (150 m)

Lower subsuite - multicolored aleurolites (greenish-grey, grey, dark grey, chocolate-brown), fissile, sometimes calcareous, rarely fine-grained sandstone, clayey limestone (245 m)

Kondyor suite - grey and black aleurolites, fine- and medium-grained, sugary grained quartz sandstone, rarely gravelites (242 m)

Early riphean intrusive formations

Dikes and dike shaped bodies of the subalkaline pegmatoid granites; dikes of the subalkaline granites, leucocratic fine-grained ($\varepsilon\tau\gamma$) graphic granites ($\rho\gamma$), and granitic pegmatoids (ρ)

Early proterozoic intrusive formations

Kondyor complex

Dunites (δ), dunite-pegmatites ($\rho\delta$), clinopyroxenites (υ)

Early archaean intrusive formations

gneissoid plagiogranites

Marble sequence - dolomitic marbles, biotitic, biotite-bearing slates, quartzites, rarely two-pyroxene, amphibolic and amphibole-biotitic slates (366 m)

Gneiss sequence - biotitic, biotite-bearing, almandine-biotitic gneisses, amphibolites, rarely dolomitic marbles (more than 522 m)

poorly defined metamorphic formations (only at the cuts)

Aldan complex

Third subcomplex: dikes of alkaline syenites ($E\xi^3$) and their pegmatites ($\rho E\xi^3$), feldspathoid syenites ($\varphi\xi^3$) and their pegmatites ($\rho\varphi\xi^3$), alkaline granites ($E\gamma^3$)

Second subcomplex: Second phase - subalkaline quartzose monzodiorites ($q\mu_2^2$), subalkaline diorites (μ^2_2), dikes of subalkaline quartzose diorites, alkali-feldspar syenites (ξ^2_2) and monzodiorites (μ_2^2), first phase - gabbro (ν_1^2), often melanocratic banded, subalkaline kosvites ($\tau\upsilon$), dikes of kosvites and gabbro

First subcomplex: second phase - dikes of a) explosion breccias and б) rhyolite tuffs (λ_2^1); first phase - sills and dikes of subalkaline diorite porphyrites ($\mu\pi_1^1$), dikes of lamprophyre (χ_1^1), subalkaline diorites (μ_1^1), trachyandesites ($\tau\alpha_1^1$), vent trachyandesites with xenoliths of host rocks ($\tau\alpha_1^1$), dikes of trachybasalts ($\tau\beta_1^1$)

Metasomatites: titanomagnetite-phlogopite-clinopyroxene, titanomagnetite-amphibole-clinopyroxene and feldspathic-phlogopite-aegirin-diopside ribs and stringers (mt^{cpx}): a) bodies in scale, б) bodies out of scale, в) dispersed dissemination of green diopside, г) dispersed stringers of green diopside; olivinized and diopsidized rocks (ol-dp), a) dissemination of secondary olivine, б) dissemination of secondary diopside; titano-magnetitized rocks (tm); skarns: garnet-diopside (sk^{dp}), spinel-monticellite (sk^{mnt}), spinel-forsterite (sk^{fo}), garnet-vesuvian (sk^{v}), amphibole-magnetite (sh^{mt}); periscarnic feldspathic-clinopyroxene metasomatites ($mt^{ps\text{-}cpx}$); greisens (qr), sulfidized and limonitized rocks (s-li); dispersed vermiculite-montmorillonite veinlet (mt^{mm}); vein of malachite-bearing metasomatites (ma)

Dunites: medium-fine-grained a), medium-fine-grained porphyry-shaped b)

kosvites (a), clinopyroxenites (b), gabbro (c)

Subalkalic quartzose diorites (a), subalkalic fine-grained diorites (b) and medium-grained (c), quartzose monzodiorites (d), subalkalic dioritic porphyrites (q), gneissoid plagiogranites (e)

Crystalline slates

Dolomitic marbles and calciphyres: illustrated in the map scale (a), unillustrated in the map scale (b)

Chocolate-brown aleurolites

Contact hornfels (1), and hornfelsed rocks (2) and pyroxene-hornblende (a) and muscovite-hornblende (b) facies

Content of chromite and titanomagnetite in dunites 2-5 % (a), > 5-7 % (b)

Zones of lenticular-stringer titanomagnetite-chromite mineralization, determined in the original bedding (a) and from diluvial fragments (b)

Cataclasites (a), milonites (b),poorly defined tectonites (c); foliated and clastated rocks

Stratification of sedimentary sequences, decoded at aerial laser scanning

Banding in gabbro and kosvites

Contours of metasomatite formation fields with degree of the host rocks saturation by metasomatites bodies 10-30 % (a) and 30-60 % (b)

Contours of the metasomatite formation fields, comprising 60-90 % of the rock volume, determined by the ground magnetometry

Contours of the formation fields of dunite-pegmatite bodies (dunite-pegmatites comprise 20-40 % of rock volume)

KvP-N,? Paleogene-miocene (?) weathering crust (on the separate overlay)

Boundaries of formations having different age : reliable (a), probable (b)

Facies boundaries

Boundaries of metasomatites and metasomatically altered rocks

Boundary of vent

Disjunctive dislocation

connected with ring structure formation:

radial, centroclinal, periclinal

other

reliable a), probable b)

structural elements orientation

inclined bedding: of layers (a), joints and fractures (b), of dikes (c), of boundaries of geological bodies (d), gneissic banding (e)

Vertical bedding of layers (a), dikes(b), boundaries of geological bodies (c)

Horizontal bedding of layers (a), joints (b), sills (c)

Drillholes: 2 - hole # ; in column - indices of main exposed pre-quaternary units, figures - depth of their bedding, m

Drill hole, projected into section plane

ΔT and Δg curves in sections lines

Units relationships (only in legend and stratigraphic columns)

Stratigraphic concordants, transverses

Undefined (tectonic boundaries, unobserved relationships)

4.1. GEOCHRONOLGICAL DATA FROM ROCKS AND PGM IN THE KONDYOR MASSIF

The age of Kondyor massif and stages of its formation are widely discussed in the literature (Table 4.1). Mainly it is related to the ultramafic rocks of the Kondyor complex, from Archaea to Cretaceous. Observation of chromespinelides and PGM in the middle Riphean sandstones in distance of 30 km from Kondyor massif is indirect geological evidence for Proterozoic age of dunites (Geology…, 1994). At the same time, there is not enough data of similarity of chromespinelides and PGM of the middle Riphean sandstones with dunites of Kondyor massif.

Osmium isotope data give a mantle model age about 260-373 Ma for PGM, that doesn't match with any other geochronological data obtained for magmatic and metasomatic rocks (Table 4.1). At the same time the age of isoferroplatinum and sperrylite inferred by the ^{190}Pt-^{4}He method, around 125±6 Ma, is in a good accordance with the most part of existing geochronological data of magmatic rocks of Aldanian complex and their metasomatic derivative in dunites.

4.2. DUNITES

The most typical Kondyor dunites, slightly modified by secondary processes, are located on the contact with pyroxenites in the Dvuglavy stream valley (Fig. 4.1) and in central part of Korotysh stream valley (Fig. 4.2).

Dunites are slightly modified serpentinized light-brown and dark-grey coloured rocks, and sometimes 15-25% serpentinized rocks of green-brown colour. Main volume of dunites consists of fine- or medium-grained, sometimes porphyry rock types of hypidiomorphic texture and massive structure. Dunites mineral composition is characterized by olivine predominance (Fa = 7.5 – 12.5%) and rare inclusions of clinopyroxene. There were also found (in smaller amounts): titanomagnetite, ilmenite, pyrite, chalcopyrite, pyrrhotite, pentlandite, covellite, marcasite, zinc, copper, lead and antimony.

On the north contact by the Dvuglavy stream dunites are almost fully fine-grained, with well-faceted grains of olivine and rare big (2.5 - 6 mm) xenomorphic olivine impregnations (Fig. 4.1).

In the direction to the "dunite-core" of the massif, in Korotysh stream, sizes of grains in fine- and medium-grained dunites slightly increase. Inclusions of up to 10 mm sized olivines are partially faceted, often elongated and sometimes have xenomorphic shape. Microinclusions of chrome-magnetite and clinopyroxene can be found in these grains.

Amount of chromospinelide in dunites is about 1-2%. It is scattered in the rock volume as small (0.1 – 0.4 mm) well-faceted crystals. Relatively bigger (more than 0.5 mm) crystals are connected with interstitia of olivine. Sometimes chromitite schliers of up to 15 cm size are found. Variations of chemical composition in chromospinelides are: $Fe^{+2}/Fe^{+2}+Mg$ from 0.5 to 0.8 and $Cr/Cr+Al+Fe^{+3}$ from 0.2 to 0.7.

Analysis of major and minor elements in "tempered glass" on the place of melted mineral inclusions in chromospinelides (Fig. 4.3) were conducted. Results of "tempered glass" analysis show, that chromespinelides were crystallizing under influence of picritic and picrobazaltic alkaline magma (Fig. 4.4). During research of "tempered glass" with ion probe (CAMECA IMS df) information of increased amount of water (up to 0.54 wt.%) was received. Estimated modeling with use of "tempered glass" composition data shows, that crystallisation of Kondyor chromospinelides and dunites was occurred with participation of water-rich magma and minimal temperatures about 1230°C [Simonov, Prikhod'ko et al., 2010].

Table 4.1. Summary table of geochronological data obtained for rocks (minerals) of Kondyor massif

Rock (minerals)	Age, Ma	Method	Reference
Subalkaline granites	1593±23	Rb-Sr	Emel'yanenko, 1994
-.-	131±3	U-Pb (zircon)	Mochalov (under preparation)
Kondyor complex			
Dunites	60-80	Rb-Sr	El'yanov, Andreev, 1991
-.-	149±20; 137±16; 125±12	Rb-Sr	Orlova et al., 1978
-.-	119±160	Rb-Sr	Pushkarev et al., 2002
-.-	Late Riphean	Paleomagnetic	Karetnikov, 2006
-.-	2477±18; 1885±52; 176±1.2; 143±2	U-Pb (zircon)	Malitch et al., 2012
-.-	1895±50; 390±12; 126±4	U-Pb (zircon)	Ronkin et al., 2013
-.-	125±2	U-Pb (baddeleyite)	-.-
Pyroxenite	648	Rb-Sr	Zlenko, 1961
-.-	132±8	Rb-Sr	Pushkarev et al., 2002
Aldanian complex			
Kosvite	650; 250; 107	K-Ar	El'yanov, Andreev, 1991
-.-	141; 140; 128; 113; 86	K-Ar	Nekrasov et al., 1994
-.-	Early Cretaceous	Paleomagnetic	Karetnikov, 2006
Hornblendite	171±9; 151±8	K-Ar	Pushkarev et al., 2002
Gabbro	70	K-Ar	Orlova et al., 1978
Shonkinite	120±5	K-Ar	Orlova et al., 1978
Ijolite	83; 93	K-Ar	-.-
Nepheline-syenite pegmatite	110±5	K-Ar	Orlova et al., 1978
Alkaline pegmatite	340; 130; 100	-.-	-.-
-.-	90	-.-	El'yanov, Moralev, 1973
-.-	168	-.-	Nekrasov et al., 1994
-.-	115±6	-.-	Pushkarev et al., 2002
Syenodiorite	133±5; 113; 98	K-Ar	Orlova et al., 1978
Syenodiorite	185	-.-	Andreev, 1987
Metasomatites on dunites			
Biotite-pyroxenite ?	120±1	^{39}Ar-^{40}Ar	Cabri et al., 1998
-.-	126.7±0.8	Rb-Sr	Efimov et al., 2012
-.-	131±35; 137±26	Sm-Nd	-.-
PGM			
PGM (chromitites, «schlich PGM»)	373; 315	^{187}Os-^{188}Os	Malitch, Thalhammer, 2002
-.-	370; 315; 260	^{187}Os-^{188}Os	Kostoyanov, 1998
Isoferroplatinum (dunites, chromitites, «schlich PGM»)	125±6	^{190}Pt-^{4}He	Shukolyukov et al., 2014
Isoferroplatinum, twin-crystals (pyroxenite metasomatities; «schlich PGM»)	125±6	^{190}Pt-^{4}He	-.-
Sperrylite «schlich PGM»	122±6	-.-	-.-

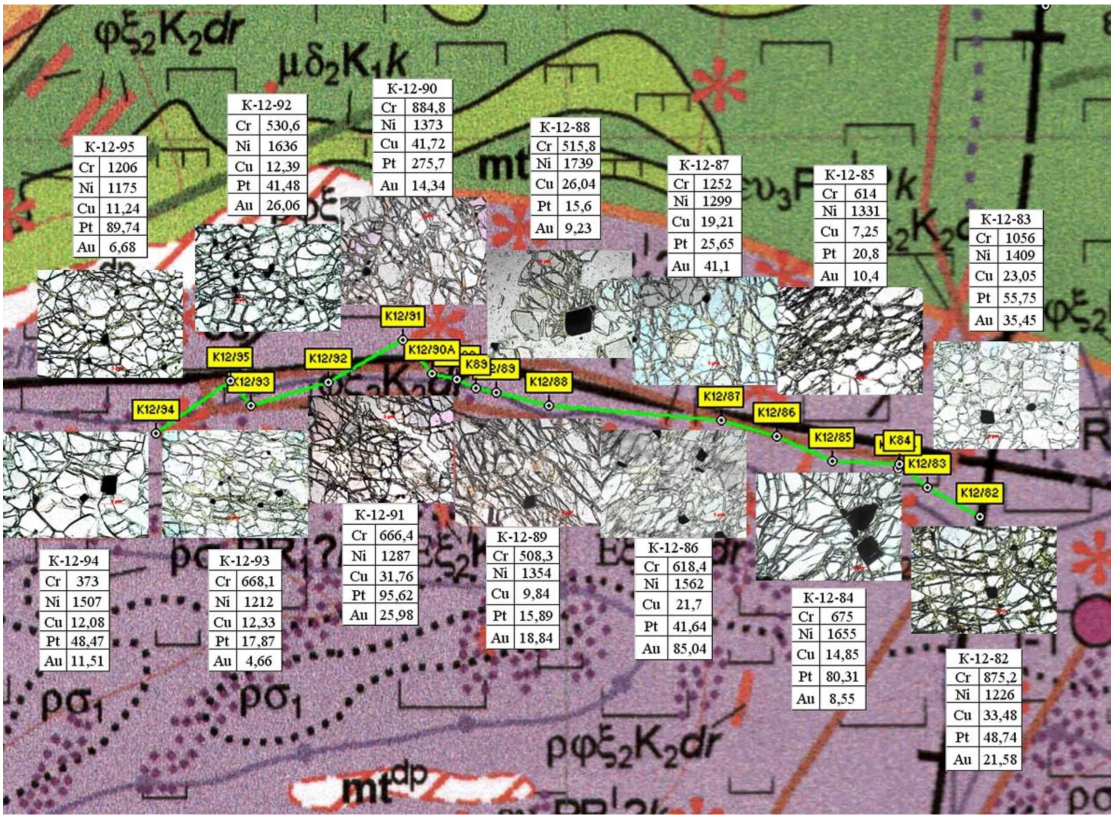


Fig. 4.1. Dunites in the Dvuglavy stream valley. Microsections of dunites between observation points (K12/82: N 57°36’331”, E 134°39’608”; K12/94: N 57°36’390”, E 134°38’423”). Amounts in the tables are in ppm for Cr, Ni, Cu and in ppb for Pt, Au (ICP-MS, ITaG FEB RAS)

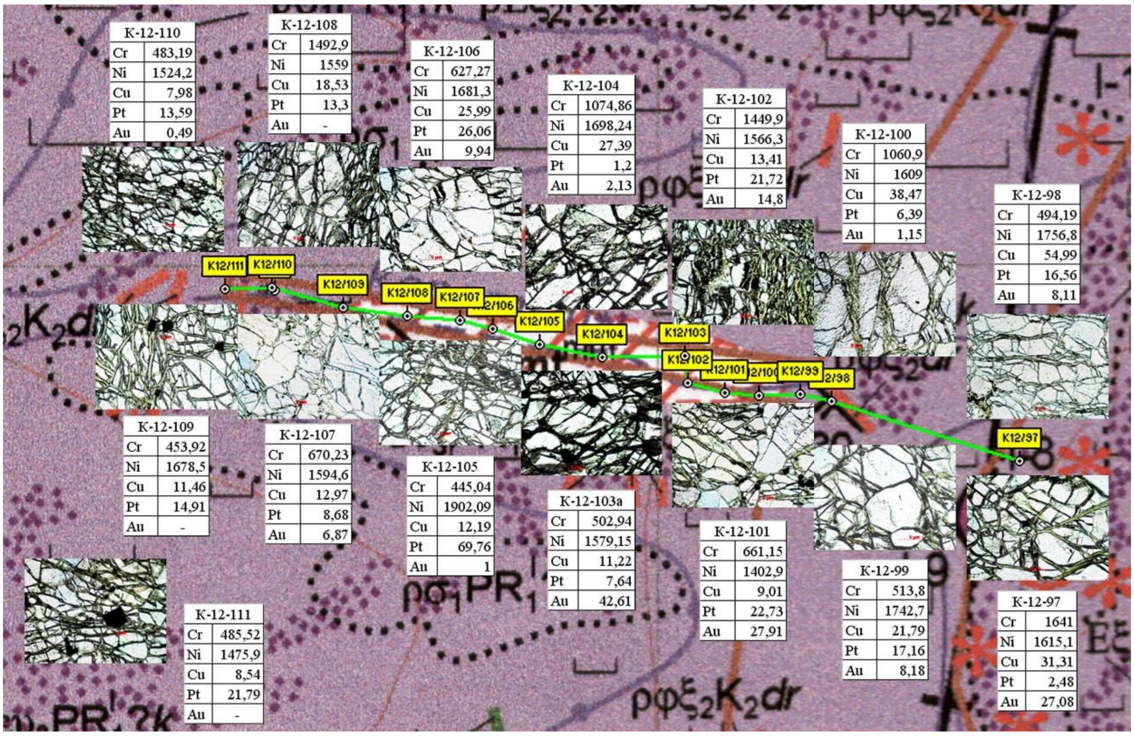


Fig. 4.2.Dunites in the Korotysh stream valley. Microsections of dunites between observation points (K12/97: N 57°35’931”, E 134°39’547”; K12/111: N 57°36’062”, E 134°38’375”). Amounts in the tables are in ppm for Cr, Ni, Cu and in ppb for Pt, Au (ICP-MS, ITaG FEB RAS)

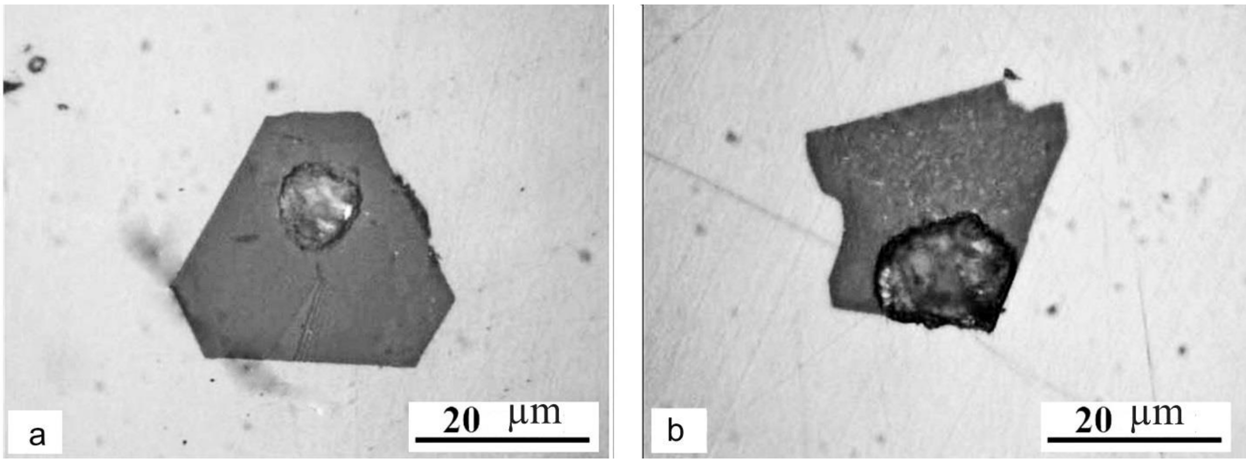


Fig. 4.3. «Tempered glass» from melted mineral inclusions in chromospinelides

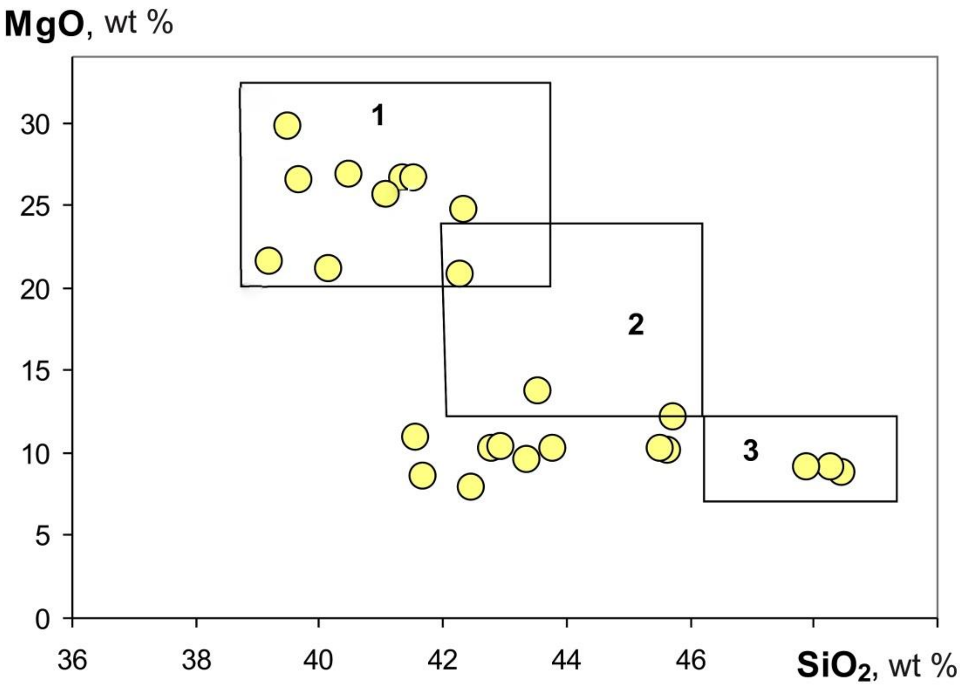


Fig. 4.4. MgO – SiO_2 diagram for «tempered glass» from melted mineral inclusions in dunite chromospinelides, rocks
1 – picrites; 2 – picrobasalts; 3 – olivine basalts

4.3. ALKALINE PEGMATITES OF KONDYOR MASSIF

Alkaline pegmatites formed vein-like bodies with the thickness up to several meters. Along the strike the veins trace for tens of meters (Fig. 4.5, 4.6) Internal structure of pegmatites differs. There are veins with clearly defined symmetrical zoning. The marginal parts of such pegmatites are composed of large grains of feldspar, nepheline, aegerine. The crystals have subperpendicular orientation to the contact plane of pegmatite with the host-rocks. This indicates that the early stage of formation of pegmatite is characterized with secretion mechanism of filling the vein. The central part of the vein is usually composed of different orientated mineral aggregates.

The most common are syenite type pegmatites, less frequently bodies of nepheline-syenites can be observed. In the blocky breakdown fragments of significantly nepheline-aegirine rocks can be found.

The swarm of veins located in the streambed of Anomalniy creek is of special interest. They don't have coarse-grained texture typical for other pegmatites and are composed of fine-grained aggregates of the cancrinite group (Fig. 4.7 –1). The other characteristic feature of these pegmatites is extremely small amount of mafic minerals (aegirine and amphibole) and the noticeable development of sulfides of copper and iron..

In most cases the most common minerals of pegmatites are potassium feldspar, albite, nepheline, aegerine, arfvedsonite (Tabl 4.-4.2). Typical minor minerals are sodium zeolites (natrolite, analcime, and others), minerals of group of lamprophyllite, cancrinite and eudialyte, titanite (Fig. 4.7 – 2). In some pegmatites these "minor" minerals form singnificant accumulations and can play the role of main phases. It seems that this is more typical for the rocks that had intensive low-temperature hydrothermal alteration, for example, for aforementioned significantly cancrinite veins. Macroscopically "albite" areas of rock in some pegmatites are often composed of newly formed analcime and, in smaller amount, of relics of feldspars.

Table 4.2. Alkaline minerals of Kondyor massif

Mineral	Formula
Potassium feldspar	$K[AlSi_3O_8]$
Albite	$Na[AlSi_3O_8]$
nepheline	$KNa_3[AlSiO_4]_3$
Aegirine	$NaFe^{3+}[Si_2O_6]$
Arfvedsonite	$NaNa_2(Fe_4Fe)[Si_8O_{22}](OH)_2$
Lamprophyllite	$Na_2Sr_2Ti_3[Si_2O_7]_2O_2(OH)_2$
Barytolamprophyllite	$KNa_3Ba_2Ti_3[Si_2O_7]_2O_4$
Eudialyte	$Na_{16}Ca_6Fe_3Zr_3[Si_3O_9]_2[Si_9O_{27}]_2(OH)_4$
Andrianovite	$Na_{12}(K,Sr,Ce)_3Ca_6Mn_3Zr_3Nb[Si_{25}O_{73}](O,H_2O,OH)_5$
Titanite	$CaTi[SiO_4]O$
Vishnevite	$(Na, K)_8[Al_6Si_6O_{24}](SO_4, CO_3)\times 2H_2O$
Bobtraillite	$Na_{13}Sr_{11}(Zr_{13}Y)(B_6Si_{42}O_{132})(OH)_{12}\times 12H_2O$
Elpidite	$Na_2Zr[Si_6O_{15}]\times 3H_2O$
Catapleiite	$Na_2Zr[Si_3O_9]\times 2H_2O$
Apatite	$Ca_5(PO_4)_3(OH)$
Fluorstrophite	$SrCaSr_3(PO_4)_3F$
Monazite-(Ce)	$Ce(PO_4)$
Natrolite	$Na_2[Al_2Si_3O_{10}]\times 2H_2O$
Analcime	$Na[AlSi_2O_6]\times H_2O$

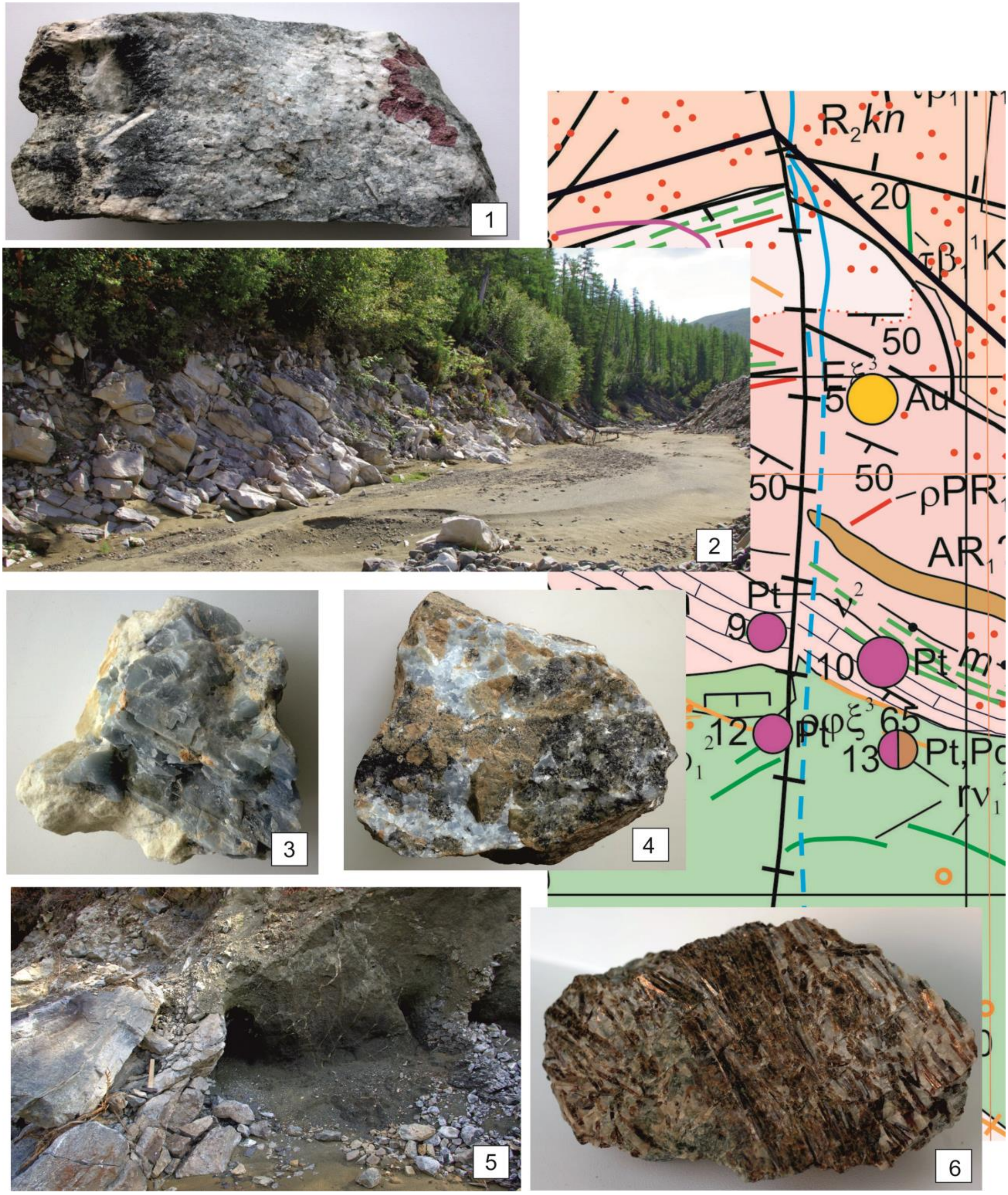
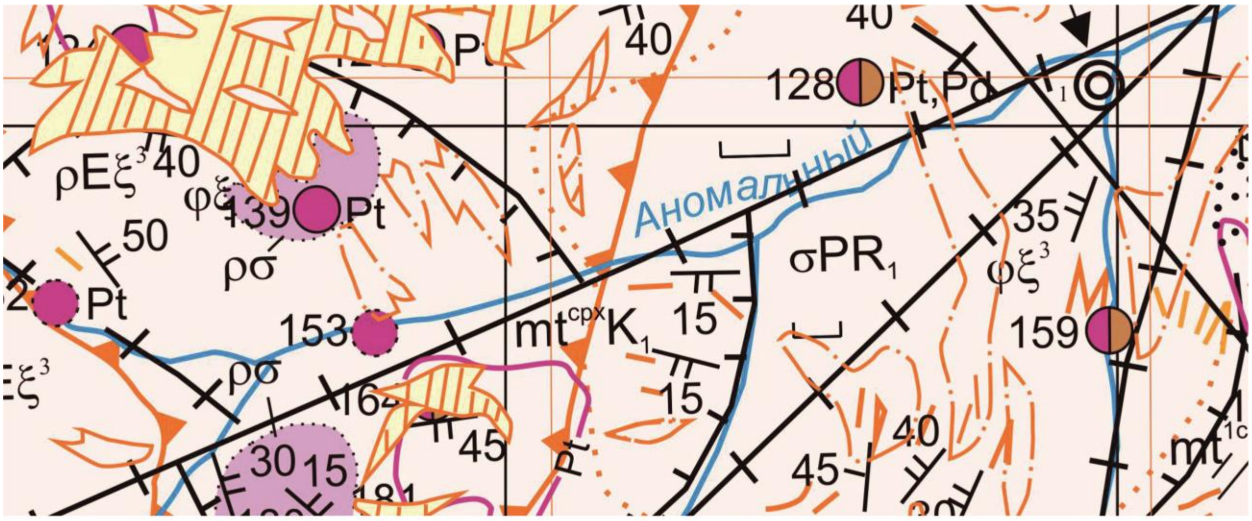


Fig. 4.5. Distribution of alkaline rocks in the canyon of the Kondyor Ridge
1. Zoned eudialyte-aegerin-albite pegmatite. 2. Calciphyres (calcite, forsterite, pyroxene, brucite, dolomite, spinel, etc.) in the exocontact of ultramafic and alkaline rocks. 3. Veinlet of blue calcite in calciphyres. 4. Perovskite-spinel-calcite- monticellite scarn. 5. Vein of aegerin-nephelin-feldspar pegmatite with lamprophyllite in pyroxene. 6. Lamprophyllite segregations.



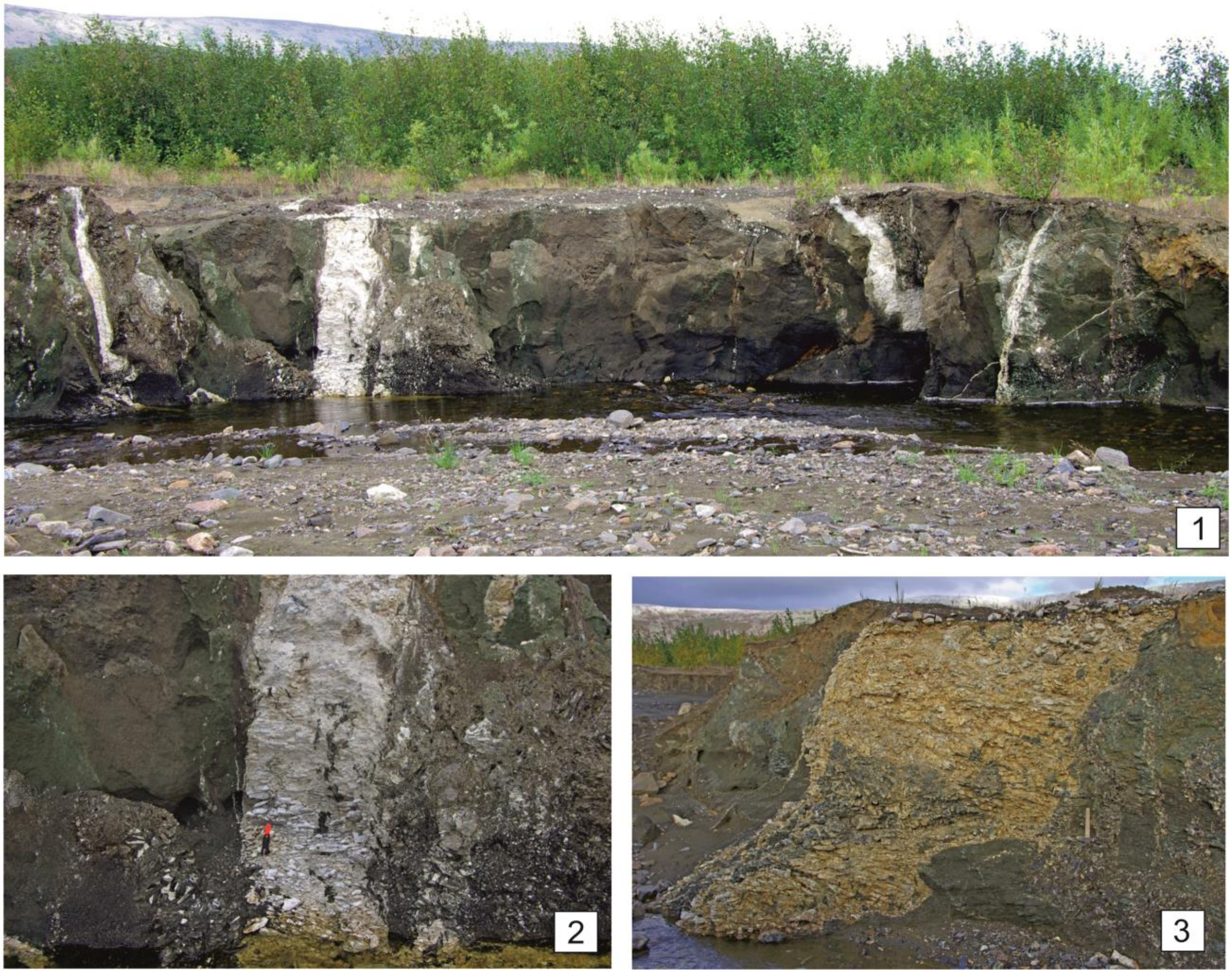


Fig. 4.6. Distribution of alkaline rocks within dunites of trib. Anomalniy

1. Veins of alkaline pegmatites. 2. Syenite-pegmatite in kosvites. In the rim of pegmatite are zones of refined kosvites that are made from coarse-grained phlogopite. 3. Vein of significantly vishnevite pegmatite

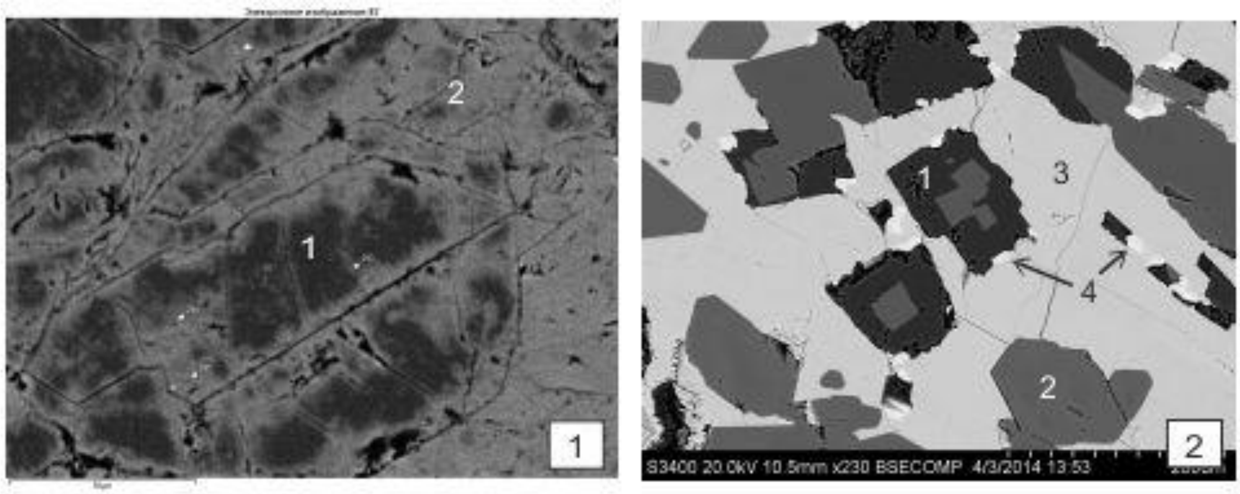


Fig. 4.7. Thin sections of alcaline pegmatites
1) 1 – vishnevite – (Na); 2 – vishnevite – (K). 2) 1 –relicts of potassium feldsapr in albite-analcime agreggate; 2- arfvedsonite; 3 – lamprophyllite; 4 – barytolamprophyllite

5. OCCURRENCE OF PLATINUM METALS

5.1. ORE-BEARING DUNITES

Experimental open-cut mine for mining platinum ore was made 6 years ago with the purpose to calculate the content of precious metal and to develop technology of beneficiation (Fig. 5.1).

Fig. 5.1. Open-cut mine of original platinum ore in the upper course of trib. Maliy. Medium-coarsegrained dunites are cut by the vein of alkaline amphibole-cancrinite-plagiocalse-nepheline pegmatite. Dip of vein SW 205°, strike 50°

The open-cut mine is located on the left bank of Maliy creek (upper course). This area is characterized with increase of chromespinelide schlieres with abundant allocations of Pt-Fe alloys (Fig. 5.2). The removed rock volume is about 1000 tons. It is known that after beneficiation 26 kg of "schlich" platinum was obtained. Thus, the average concentration of metal in the rock is 20-25 g/t.

Fig. 5.2. Pt-metal rich schlier of chromespinelides. Content of platinum 2-4%

During 2012-2013, samples of the original ore were collected at the same place by the company "Mexanobr Engineering" for the developing of a new technological scheme of platinum beneficiation. Below the results of study of these ore-bearing dunites are presented.

Petrographic characteristics.

Dunites mostly are medium-grained and always have relatively small amount of fine-grained olivine. In some samples separate porphyric impregnations of large olivine aggregates (more than 10 mm) can be observed. Texture is hypidiomorphic with elements of porphyritic. The texture is massive.

Mainly small and medium-sized grains of olivine are presented by isometric and hypidiomorphic aggregates (Fig. 5.3a). As their size increases, a tendency of deterioration of the degree of idiomorphism (Fig. 5.3b) up to formation of xenomorphic borders. Quite often polysynthetic twins of pressure can be observed in olivine aggregates (Fig. 5.3a). Sometimes (several thin sections) very small (parts of mm) areas of subparallel system of thin lammels of disintegration of ore mineral of lamellar and dendritic shape can be observed (Fig. 5.3c).

Practically all samples have strong fracturing that is accompanied by formation of thin veinlets of serpentine, sometimes with boulingite, that formed the loop-like texture (Fig. 5.3a,b, d-f). Intensity of this secondary process is noticeable increasing up to the full pseudomorph on the contact with more rare (more than 1 mm) fractures filled with the zoned veins of amphibole-serpentine composition (Fig. 5.3 d-f).

There are two generations of chromespinelide mineralization. The first generation is presented by thin accessory impregnation of chromite that is widely spread in the all samples of dunite (average content around 1 %). Based on morphological and texture features 3 morphological types of thin accessory chromites can be distinguished:

1) rare very thin grains that usually have isometric or cubic shape as inclusions in olivine;
2) dispersed and irregular distributed hypidiomorphic grains of chromite in interstitia of olivine individuals;
3) irregular distributed small hypidiomorphic grains, allocated in fractures of brittle deformation. This fractures often cut olivine aggregates.

The second type of chromite mineralization is so called “ore-bearing” chromites. It has very irregular distribution and form small (length: up to 10-30 cm; width: from several mm to 10 cm) schlieres of vein-like chromitites of different shape. Morphology of the contact of chromitite body with the host-rock can change from sharp to relatively smooth, to the fuzzy, complex and gradual.

Platinum group minerals (PGM).

Most often PGMs are located in separate segregation of chromites. In ore-bearing aggregates PGMs form some kind of “cement” between chromite grains (Fig. 5.4). This “cement” mainly consists from Pt-Fe alloys, and also from small amount of various sulfides and arsenides of PGE. In enriched aggregates of chromite content of PGMs is from 10 to 40 %. After disintegration of these aggregates Pt-Fe alloys are released as delicate reticulated wire-like splintery grains (Fig. 5.5). Chromite is quite often found as inclusions in these Pt-Fe alloys.

In small fractions PGM gradually becomes more isometric. Lumpy isometric aggregates appear Fig. 5.6). In very small size classes almost all particles have isometric shape. Sometimes cubic crystals are observed (Fig. 5.7).

In general, there are three morphological and structural types of platinum group minerals.

The first (PGM1) is presented by dispersed, irregularly distributed, isometric and hypidiomorphic impregnations (from several microns to tens of microns) that mainly are inclusions in chromites (Fig. 5.8 a-e). Rarely grains of this generation can be found directly in dunites, outside the chromite segregations. However this generation has spatial connection with chromites (or disseminated or schlieren-like) anyway.

The second (PGM2), more common generation of PGM forms relatively large (hundreds of microns) disseminated aggregates (sometimes their agglomerations) mainly of prismatic or polygonal shape, confined in fractures in chromite grains or interstitia (Fig. 5.8 a-c).

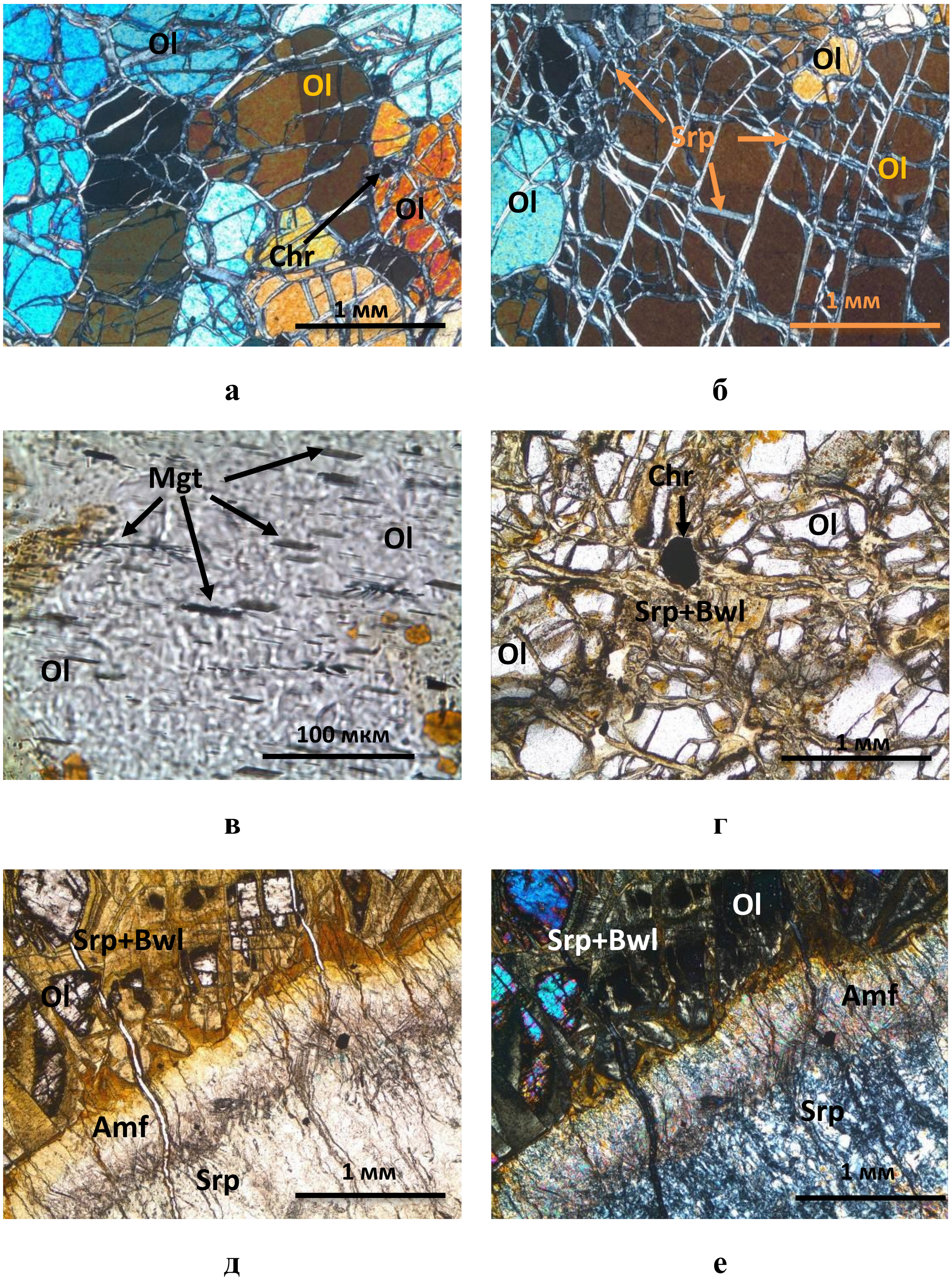


Fig. 5.3. Medium-grained dunites with separate large aggregates of olivine with impregnation of different sizes.

Hypidiomorphic texture. (a) with elements of porphiric and looped (a,b,d). Massive structure. a – medium-grained dunite with lopped structure (thin section, with analyser); (b) – large aggregate of olivine (thin section, with analyser); (c) – the zone with lammels (texture of disintegration of magnetite in olivine grains) (thin section, without analyser); (d,e,f) – replacement of olivine mineral individuals by the aggregates of serpentine, boulingite and amphibole; (e, f) – contact of dunite with vein of amphibole-serpentine composition (thin sections, f – with analyzer).

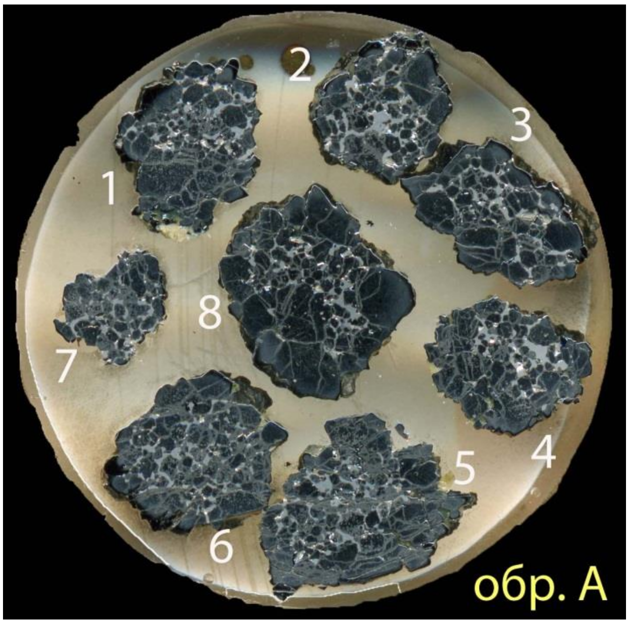


Fig. 5.4. The most typical segragations of PGM. They fulfilled xenomorphic interstitium of chromite grains (grey)
The reflected light, the diameter of the washer 25 mm, platinum content according to the mineralogical analysis of aggregates from 16% (sample #8) to 35% (sample #2).

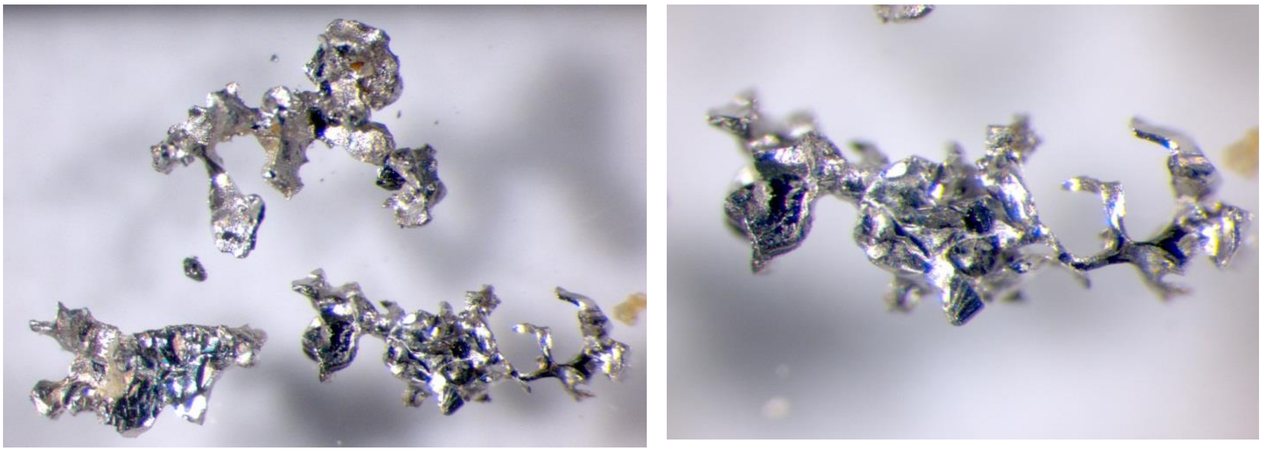


Fig. 5.5. Morphology of «free» Pt-Fe alloys. Fraction 2-5 mm

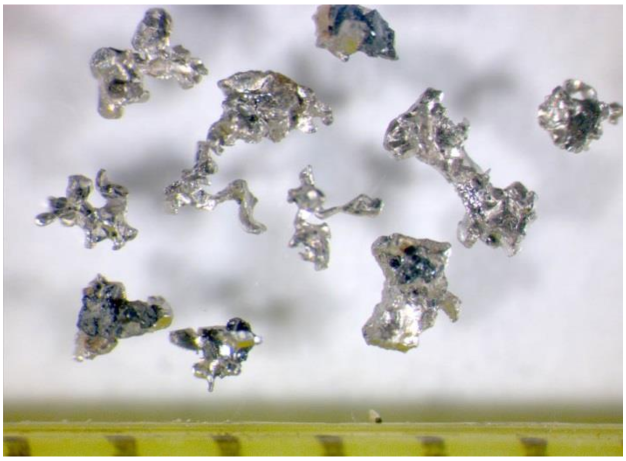


Fig. 5.6. Morphology of pieces of PGM with size 0,5-1 mm. Binocular loupe

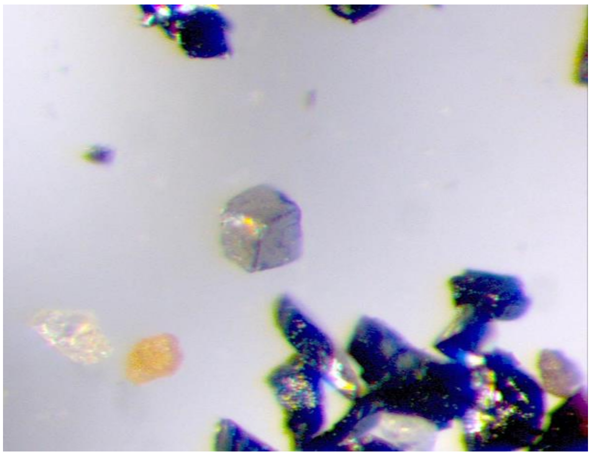
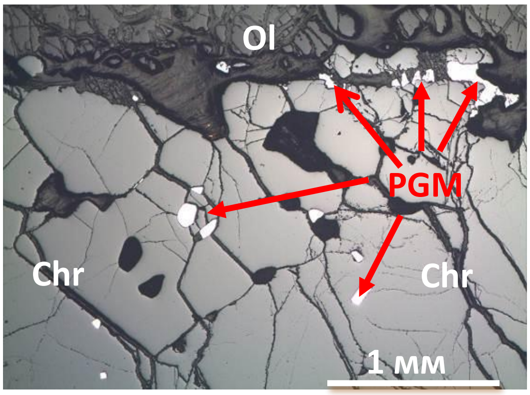


Fig. 5.7. Cubic crystal of Pt-Fe alloy in fraction 0,12-0,07 mm. Binocular loupe



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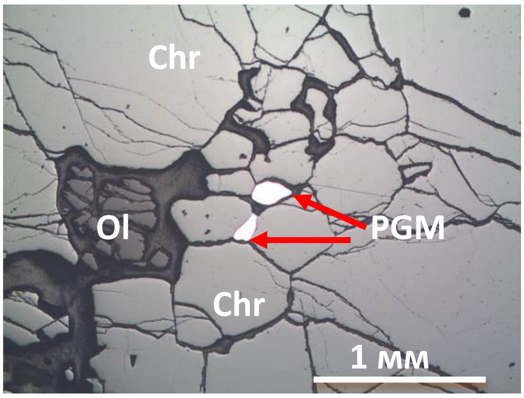

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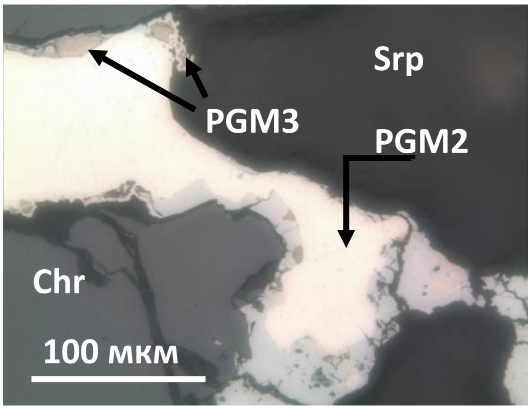

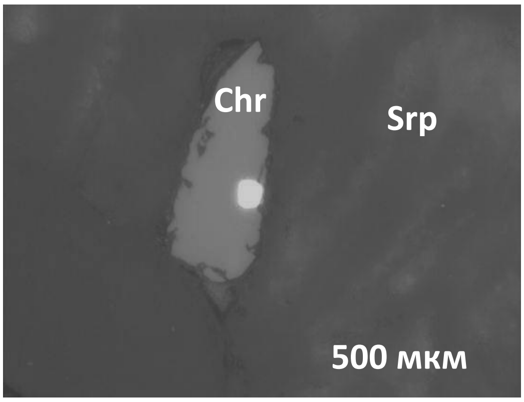

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Fig. 5.8. Manifestation of PGM in chromites
a – hypidiomorphic mineral individuals of PGM as an inclusions in chromite aggregates; hypidiomorphic and polygonal grains of PGM in fractures and interstation of ore-bearing chromite; and xenomorphic formations on the external borders of chromitite schlier;
b – polygonal formations of PGM2 (second type) in chromite;
c – xenimorphic grain of PGM2 with rims of more late minerals of PGE 3;
d – crystal grain of laurite (PGM1) in the chromite grain. All figures are in reflected light

The most rare **third (PGM3)** generation of PGM is allocated in the external border of chromite with dunite. It is presented as aggregations or single polygonal and xenomorphic grains that grow over on xenomorphic and polygonal aggregates of PGM2. Usually it is grains of polyphase composition (phases of native metals, sulfides and arsenides of PGE). Some grains reach the size of hundreds of microns (Fig. 5.8 a,c).

Relation between platinum group minerals.

Relation of PGM in original ore-bearing dunites was studied based on the **mineral composition of the final concentrate**. 7838 mineral grains from the concentrate were studied on the electron microscope by the method of automatical mineralogical analyse MLA in a random cross-section of the samples. Based on chemical composition 32 minerals were determined among these grains (Fig. 5.9). Of these, 13 refer to minerals of the platinum group metals; the total amount of them in the concentrate is 97.4% by weight. The vast number of grains in the PGM concentrate is Pt-Fe alloys (96,9 wt.%), similar in composition to isoferroplatinum Pt_3Fe (Table 5.1).

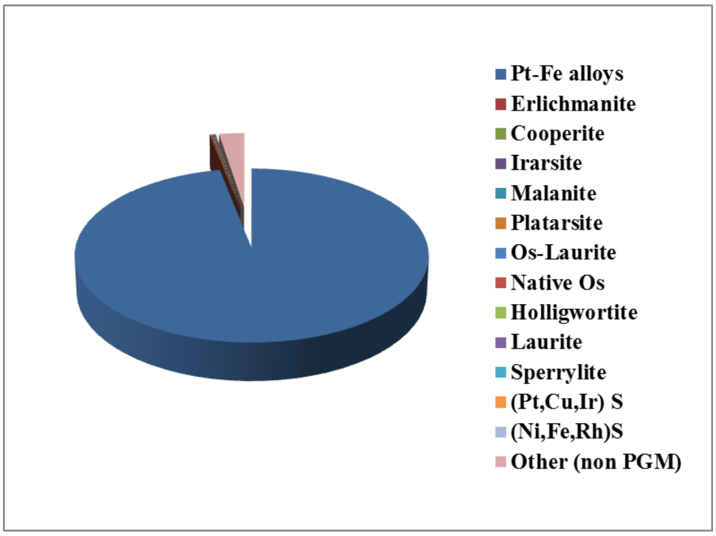


Fig. 5.9. Distribution of minerals in ore concentrate from ore-bearing dunites

The second most common mineral in concentrate is chromite with average chemical composition close to the magnesium-chromite, crystal-chemical formula $(Fe_{0.32}Mg_{0.61}Mn_{0.07})_{1.00}(Al_{0.26}Cr_{1.39}Fe_{0.35})_{2.00}O_4$. Among other significant Pt phases are erlichmanite OsS_2 (0,19%) (Table 5.2), cooperite PtS (0,12%), irarsite IrAsS (0,11%) (Table 5.3) and malanite $Cu(Pt,Ir,Rh)_2S_4$ (0,05%) (Table 5.4), total content of them is 0,47% by weight. Concentration of other Pt-metal phases does not exceed 0,02% for each of them. Moreover in the concentrate are found single grains of unnamed Pt-minerals with crystal-chemical formulas: $Pt_{3.08}Cu_{2.37}Rh_{1.28}Ir_{1.18}Os_{0.06}S_{9.04}$ and $Ni_{0.31}Fe_{0.21}Rh_{0.18}Cu_{0.13}Ir_{0.09}Pt_{0.05}S_{1.02}$.

Chemical composition of Pt-Fe alloys is characterised by high concentration of ferrum – all phases belongs to intermediate between isoferroplatinum and tetraferroplatinum (Table.5.1). Rh, Pd and Ni is constant impurity in these alloys.

Table 5.1. Chemical composition of Pt-Fe alloys (wt.%)

Pt	Rh	Pd	Fe	Ni	Total
80,28	0,73		15,99	3,01	100,01
83,66	1,17	0,76	11,99	2,42	100
84,42	1,23	0,81	11,86	1,69	100,01
87	0,38	n.d.	10,5	2,13	100,01
85,86	0,66	1,27	9,81	2,4	100
86,93	0,95	0,59	10,6	0,94	100,01
86,2	0,57	1,96	9,88	1,38	99,99
87,25	1,2	0,67	8,51	2,37	100
87,3	0,6	1,65	9,8	0,65	100
87,19	2,0	1,1	8,1	1,61	100
89,03	0,82	1,01	7,84	1,3	100
89,07	1,17	1,25	7,37	1,14	100

Table 5.2. Chemical composition of erlichmanite (wt.%)

Os	Ir	Pt	Ru	Rh	Fe	S	Total
59,63	7,22	n.d.	6,46	0,99	0,53	25,17	100
64,82	7,97	«	1,45	0,47	0,76	24,53	100
67,38	0,87	1,13	3,39	2,21	1,05	23,98	100,01
67,71	2,55	1,43	1,54	1,75	1,55	23,48	100,01
68,34	2,81	n.d.	0,34	2,52	1,27	24,72	100
68,72	2,51	«	n.d.	3,37	1,19	24,2	99,99
71,77	0,93	«	0,77	1,29	0,55	24,69	100
73,46	n.d.	0,98	0,3	n.d.	0,85	24,41	100
74,4	«	0,52	n.d.	0,32	1,06	23,7	100

Table 5.3. Chemical composition of irarsite (wt.%)

Ir	Os	Rh	Pt	Ru	Pd	Fe	As	S	total
24,42	6,8	22,78	1,37	0,48	0,65	0,42	30,25	12,85	100,02
33,54	6,69	12,84	5,14	1,28	0,8	0,8	27,7	11,23	100,02
35,2	6,57	12,56	3,18	1,44	1,17	0,87	27,76	11,24	99,99
35,31	7,76	11,39	3,85	0,78	0,96	0,72	28	11,23	100
36,95	6,82	11,84	2,76	1,06	0,84	0,79	27,58	11,36	100
38,73	9,1	8,52	2,81	0,98	0,82	0,45	27,12	11,46	99,99
40,17	6,26	10,32	2,16	0,69		0,81	28,09	11,49	99,99
42,58	6,37	7,91	3,59	0,61	0,46	1,25	26,46	10,79	100,02
46,24	10,93	1,29	4,88	n.d.	n.d.	0,84	25,36	10,44	99,98
49,6	8,53	3,27	1,72	«	«	0,66	25,86	10,36	100
50,67	8,24	3,74	1,1	«	«	0,43	25,33	10,49	100

Table 5.4. Chemical composition of malanite

Pt	Ir	Rh	Cu	S	total
30,14	22,4	10,27	12,84	24,35	100
30,47	22,54	10,61	13,2	23,18	100
31,64	22,34	9,92	12,42	23,68	100
31,91	24,92	7,35	11,4	24,43	100

5.2. OCCURRENCE OF PLATINUM METALS IN APATITE-MAGNETITE-PHLOGOPITE-PYROXENE METASOMATITES

Observation point KD-9 is located in 800 m to the south from confluence of creeks Anomalniy and Begyn and in 850 m to the east from confluence of creek Maliy in creek Begyn. Coordinates of the point are WGS84 N 57,58032°, E 134,65686°.

Observation point is presented by a rocky outcrop on the roadside (drilling floor) with extension of more than 30 m and height 2,5-3 m (Fig. 5.2.1 – 5.10). Stretching of the wall NW 330°.

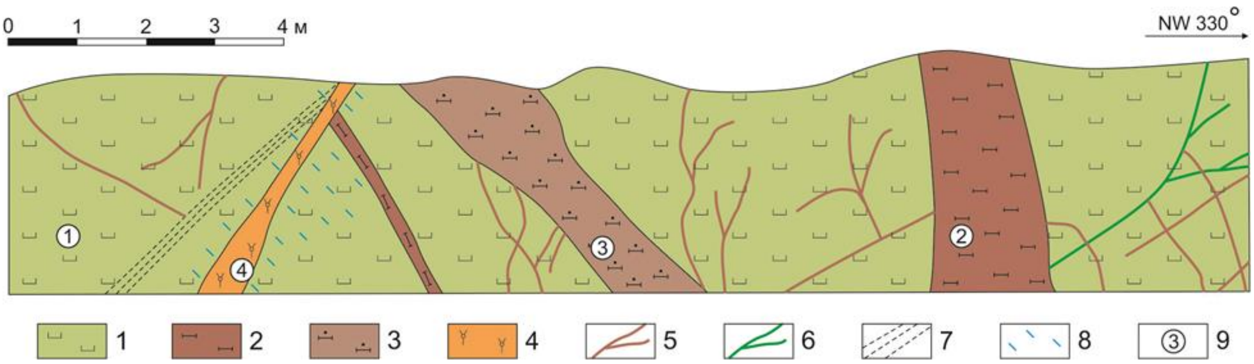


Fig. 5.2.1-5.10. Scheme of the southern-eastern part of outcrop KD-9
1 – fractured serpentinized dunites; 2 – apatite-magnetite clinopyroxenites; 3 – apatite-magnetite-phlogopite-pyroxene metasomatites; 4 –alkaline «pegmatites»; 5 – out of scaled veins and veinlets of apatite-magnetite clinopyroxenites; 6 – out of scaled veins and veinlets of chrome-diopside composition; 7 – linear zone of fractures in dunites with imposed serpenitization and amphibolitization; 8 – zeolite metasomatites on dunites; 9 – sampling points and their numbers.

Strongly fractured and varying degree serpentinized dunites can be observed in this very limited area. Steeply dipping body of apatite-magnitete clinopyroxenites (Fig. 5.10 - 2), apatite-magnetite-phlogopite-pyroxenite metasomatites (Fig. 5.10 -3) and vein of alkaline pegmatites

(Fig. 5.10 - 4) cut the dunites. Almost the entire volume of dunites is permeated by differently oriented veins and veinlets (ranging from 1 to 10-15 cm) of pyroxenites. In the northern-western part of the outcrop thin veinlets of emerald-green chrome-diopside can be observed.

Dunites (Fig. 5.10 - 1) are mainly medium- to fine-grained with hypidiomorphic-granular texture (Fig. 5.11). Sometimes texture is close to porphyritic, as in some samples porphyritic phenocrysts of olivine can be observed (Fig. 5.12). Dunite texture varies from massive to highly fractured, friable. The degree of idiomorphism of olivine grain is inversely dependent on its size. Sometimes xenomorphic borders are observed. Quite often polysynthetic twins of pressure can be detected in the olivine grains (Fig. 5.13).

Almost all the samples exhibit strong fracturing that is mainly accompanied by the development of thin veins of serpentine, sometimes with boulingite, that forms a loop-like texture (Fig. 5.14). The intensity of this secondary alteration markedly increased, up to full pseudomorphs on the contacts with more rare and thicker (more than 1 mm) fractures, composed of zoned amphibole- serpentine veins.

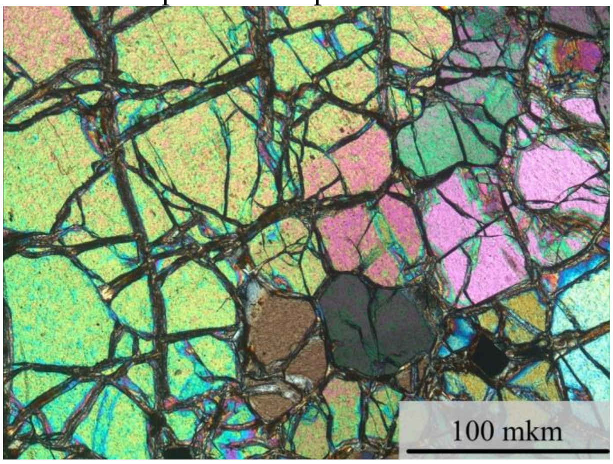


Fig. 5.11. Hypidiomorphic-granular texture of fine- middle-grained dunite

Highly fractured. Fractures are made of diverse columnar aggregate of serpentine. Dark inclusion in the right lower corner – grain of chromespinelide in interstitium. Microphotograph of the thin section, transmitted light, with analyser

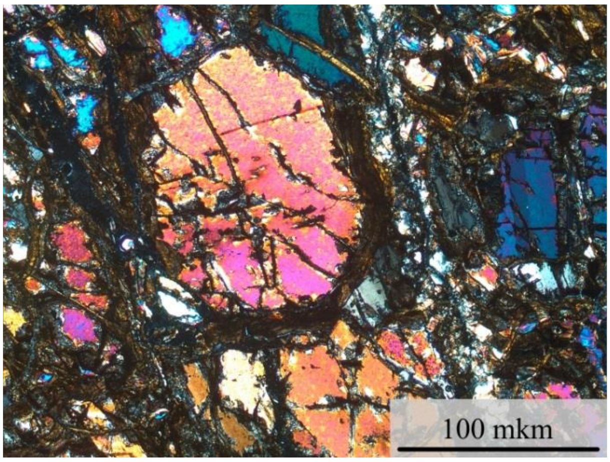


Fig. 5.12. Porphyritic phenocryst of olivine in the middle-grained strongly serpentinized dunite

Microphotograph of the thin section, transmitted light, with analyser

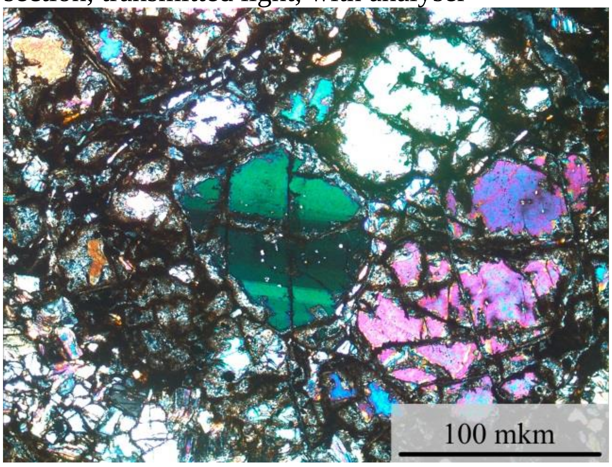


Fig. 5.13. Polysynthetic twins of pressure in olivine. Microphotograph of the thin section, transmitted light, with analyser

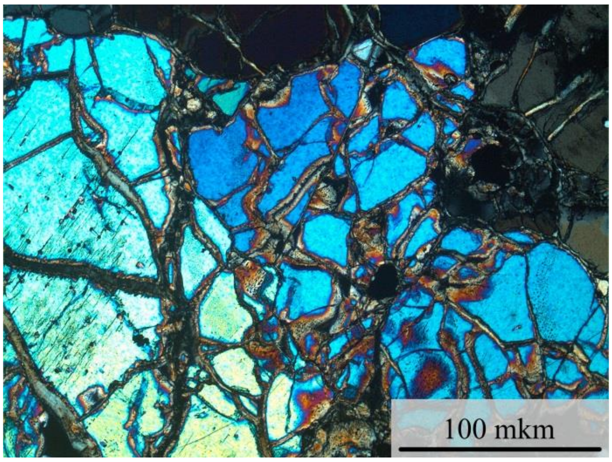


Fig. 5.14. Loop-like texture of serpentine veinlets with boulingite that fulfil fractures in the olivine grains. Microphotograph of the thin section, transmitted light, with analyser.

Accessory minerals in dunites are orthopyroxene (up to 1-2%) and chromspinelide (up to 3-5%). Based on the textural and the morphological features two generations of chromespinelides are distinguished. The first generation is usually presented by cubic or isometric finest grains, which are presented by inclusions in the olivine grains. The second one is presented by the slightly larger (in average), mainly hypidiomorphic grains that are dispersed and irregularly distributed in the interstitium of the olivine individuals (Fig. 5.11).

Apatite-magnetite clinopyroxenites (kosvites) are presented by thick (up to 2 m) dyke-like body that cuts dunites, as well as by the group of differently orientated veins and veinlets in the dunites (Fig. 5.10). Mineral composition of kosvites is independent from the size of the body. However increase of magnetite content and decrease of the grain size with decrease of the veinlet width is observed (Fig. 5.15, 5.16).

Texture of the apatite-magnetite clinopyroxenites is hypidiomorphic-granular with elements of sideronitic one. Grains of clinopyroxene (diopside) are cut by numerous fractures of cleavage. Apatite is noticed in the rock sporadically. Its role is more accessory than rock-forming. However, in some bodies content of apatite in kosvites is more significant and can rise up to 5-8%.

Magnetite is presented in two structural-morphological positions in the rock: in the form of microinclusions with high degree of idiomorphism in pyroxene, and in form of xenomorphic aggregates in the intergranular space of pyroxene.

Apatite-magnetite-phlogopite-pyroxenite metasomatites are presented within the outcrop by three vein-like bodies with bulges with thickness up to 2-2,5 m. The first body is shown on the Fig. 5.10, two others are located in the northern-western part of the outcrop and are not on the scheme. All bodies characterized with similar dip NW-N 330-350° and strike 40-50°.

Metasomatites are presented by very loose and fragile rocks of medium- and coarse-grained texture. For their mineralogical study artificial preparations with epoxy cement were made. Unfortunately original textures of the rock do not preserve in such preparation. Thus it is possible to determine only the mineralogical and granulometric composition of the rock. Optical properties are also disturbed by the increasing thickness of the preparations (Fig. 5.17, 5.18). The main mineral phase of the rock is pyroxene (around 40-50%), phlogopite and magnetite (each around 20-25%), and apatite is minor component – 5-7%.

In the southern-eastern part of the outcrop a vein of alkaline "pegmatite" is observed. Its central part is composed of theralites of olivine-nepheline-feldspar composition (Fig. 5.19). Selvages are presented by needle-like alkaline amphibole (Fig. 5.20). Theralites have medium-grained hypidiomorphic texture with massive structure. The term "pegmatite" in this case mainly stresses that there is a zonation of the vein, rather than the rock texture.

On this outcrop a zone of zeolitic alteration on dunites and vein theralites is easily defined. Zeolites form botryodial aggregates of the white colour in the fractures and voids. Within the alkaline vein, zeolitic metasomatism is presented by "spreusteinisation" of nepheline (Fig. 5.21) and by the cryptocrystalline alteration on the feldspar.

Characteristics of precious-metal mineralization of apatite-magnetite-phlogopite-pyroxenite metasomatites.

Gravity concentrates derived from mineralogical samples were used to study ore mineralization of metasomatites. The main minerals in gravity concentrate are magnetite and chromespinel; in subordinate amount: ilmenite, pyrite, chalcopyrite, sphalerite, titaniferous magnetite, titanite, loellingite and native copper. Low temperature formations are covellite that forms almost full pseudomorphs of native copper, and iron hydroxide aggregates, developing on pyrite. PGM are found in the "crushed" rock sporadically. 8 mineral species were established: cooperite, malanite, laurite, erlichmanite, irarsite, sperrylite, mertieite II, Cu-Fe-Pt alloy (ferroplatinum).

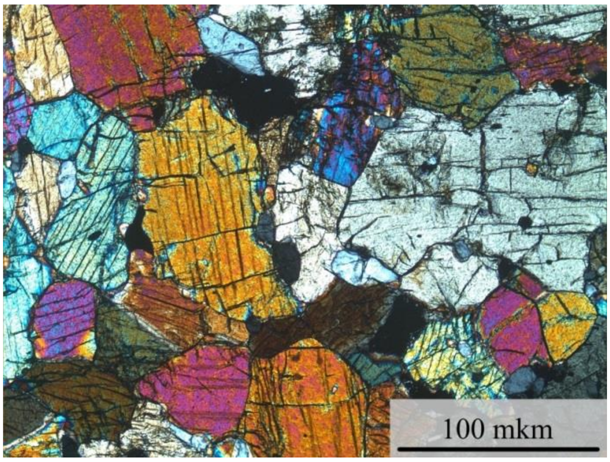


Fig. 5.15. Hypidiomorphic-granular with elements of sideronitic texture of middle-coarsegrained kosvite from dyke-like body (outcrop KD-9)
Magnetite (black) is in two positions: (1) inclusion in the pyroxene; (2) in the intergranular interstitium. Microphotograph of the thin section, transmitted light, with analyser

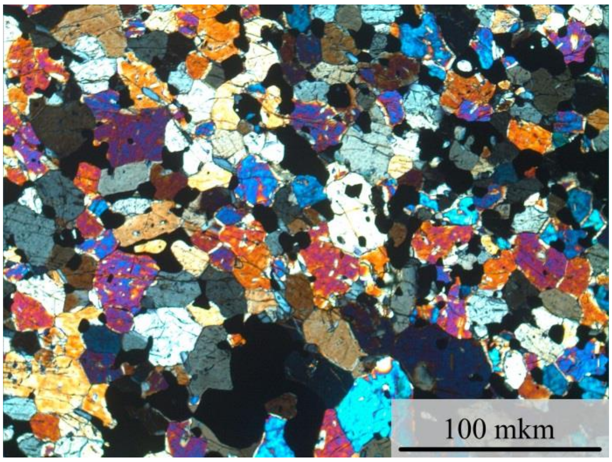


Fig. 5.16. Middle-finegrained texture of kosvites from thin veinlets
Magnetite is also in two positions. Microphotograph of the thin section, transmitted light, with analyser.

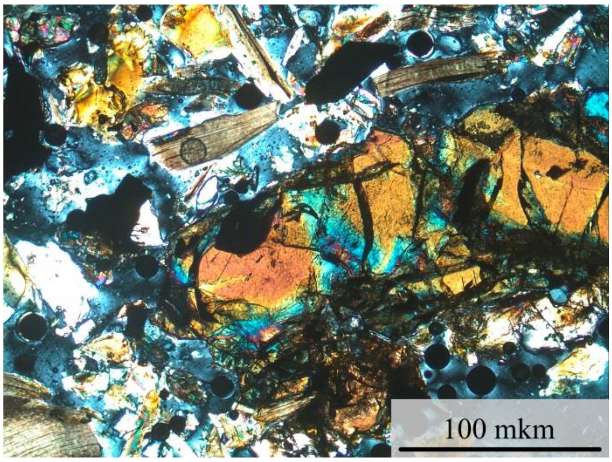


Fig. 5.17. Large aggregates of phlogopite, hypidiomorphic grains of magnetite (black) and xenomorphic grains of apatite (canary) in apatite-magnetite-phlogopite-pyroxene metasomatites
Microphotograph of the thin section, transmitted light, with analyser

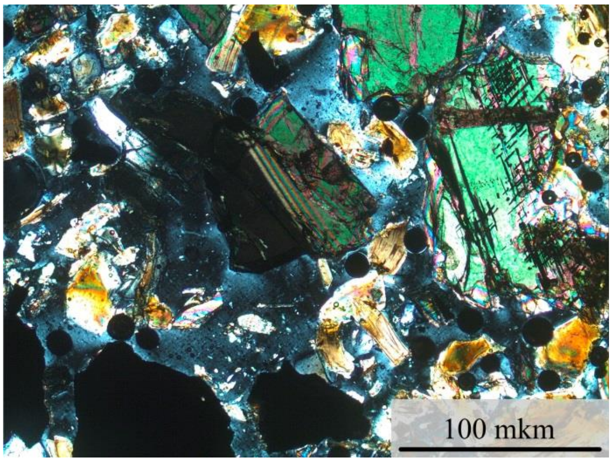


Fig. 5.18. Xenomorphic apatite (yellow) and magnetite (black) and hypidiomorphic grains of pyroxene (greenish with cleavage) from apatite-magnetite-phlogopite-pyroxene metasomatites
Microphotograph of the thin section, transmitted light, with analyser

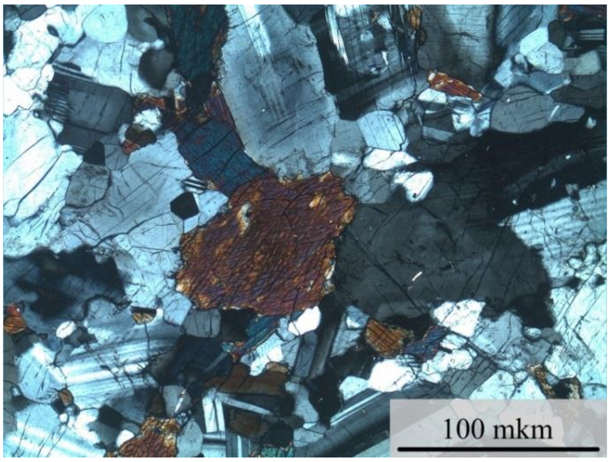


Fig. 5.19. Rocks of the central part of the alkaline vein –theralite. Nepheline and olivine are presented by xenomorphic grains Orthoclase characterizes by growth twins. Microphotograph of the thin section, transmitted light, with analyser.

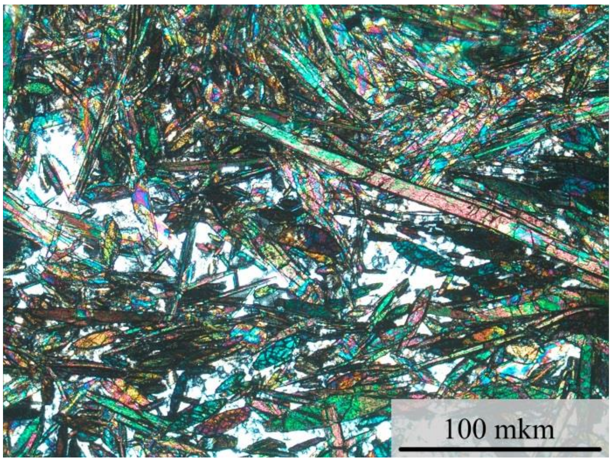


Fig. 5.20. Fineneedle-like aggregate of alkaline amphibole from selvage part of alkaline vein Microphotograph of the thin section, transmitted light, with analyser

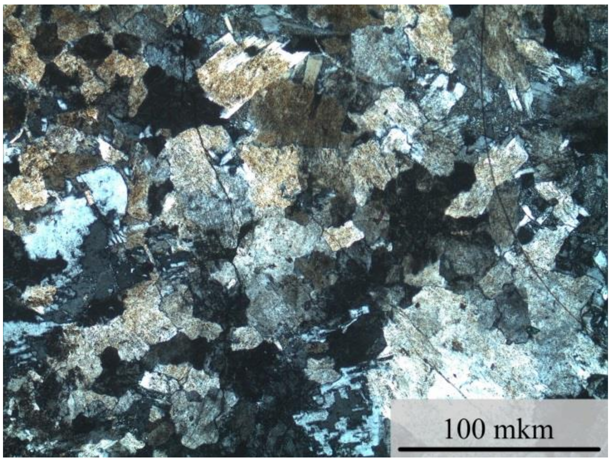


Fig. 5.21. Development of cryptocrystalline zeolites on nepheline and orthoclase in theralites of alkaline vein. Sometimes (black) aggregates of zeolites fulfil intergranular space

Cooperite is the most common mineral of platinum in the «crushed» rock. It is presented by xenomorphic and hypidiomorphic grains ranging in size from a several dozen microns to 0.3-0.4 mm. *Malanite* (Fig. 5.22A), *irarsite* (Fig. 5.22A, B, C) and osmium-ruthenium sulfides (laurite-erlichmanite series) are developing in expense of cooperite in form of inclusions of substitution (Fig. 5.22B). Chemical compositions of these minerals are shown in Table. 5.5.

Mertieite is the second most common mineral in the «crushed» rock and is presented by aggregates of intergrowth of xenomorphic grains (Fig. 5.23). Some grains have traces of brittle deformation. These aggregates are composed of fragments of grains (Fig. 5.23A). Aggregate size is up to 40 microns. The size of individual grains does not exceed 7-10 microns. Its chemical composition (Table 5.6) corresponds to stoichiometry of mertieite -II - $Pd_8(Sb,As)_3$.

Sperrylite is presented by hypidiomorphic grains of cubic habitus ranging in size up to 40 microns (Fig. 5.24A), as well as by the rims around the magnetite. Rims are also composed of aggregates of crystals of cubic habitus and have high degree of idiomorphism. Chemical composition of sperrylite is shown in Table 5.7.

Table 5.5. Chemical composition of cooperite, irarsite, malanite, laurite and erlichmanite (wt.%)

Fe	Ni	S	Cu	As	Ru	Rh	Pd	Os	Ir	Pt	total
Cooperite PtS											
n.d.	0,43	13,7	n.d.	n.d.	n.d.	0,45	1,04	n.d.	n.d.	84,4	100
«	0,64	13,4	«	«	«	0,89	1,4	«	«	83,7	100
«	0,95	13,7	«	«	«	0,95	0,71	«	«	83,7	100
«	n.d.	14,5	«	«	«	n.d.	n.d.	«	«	85,5	100
«	«	15,1	«	«	«	«	«	«	«	84,9	100
«	«	15,3	«	«	«	«	«	«	«	84,7	100
Irarsite IrAsS											
0,11	«	13,0	«	22,4	1,23	8,69	«	3,96	50,6	n.d.	100
Erlichmanite $(Os,Ru)S_2$											
n.d.	«	29,3	«	n.d.	14,69	n.d.	«	47,9	8,1	«	100
Laurite $(Ru,Os)S_2$											
«	«	37,1	«	«	38,97	«	«	23,6	n.d.	«	100
Malanite $Cu(Pt,Ir)_2S_4$											
«	«	23,9	10,7	«	n.d.	5,34	«	n.d.	28,7	31,3	100
«	«	22,9	10,5	«	«	6,56	«	«	29,4	29,5	100
«	«	23,1	10,9	«	«	5,7	«	«	29,1	31,1	100
«	«	23,3	10,9	«	«	6,1	«	«	29,4	30,3	100
«	«	23,7	11,1	«	«	6,47	«	«	25,2	32,2	100

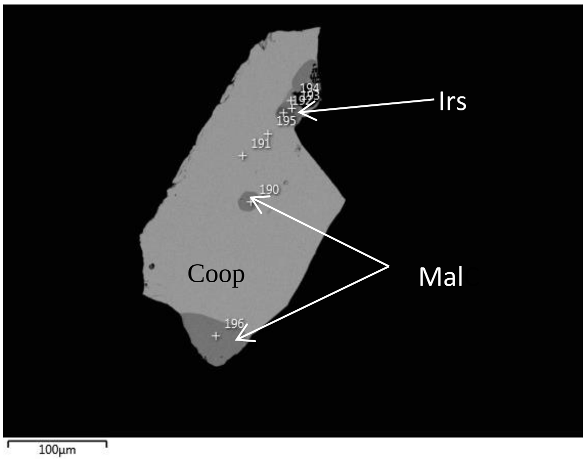
Note: n.d. – not detected

Table 5.6. Chemical composition of mertieite (wt.%)

Cu	As	Ru	Rh	Pd	Sb	total
mertieite -II $Pd_8(Sb,As)_3$						
1,05	9,28	0,39	2,88	70,6	15,8	100
1,44	9,26	0,26	2,8	70,7	15,5	100
0,5	9,63	n.d.	0,1	73,9	15,8	100
0,32	9,41	«	n.d.	75,0	15,2	100
2,18	9,37	«	«	72,3	16,1	100
n.d.	4,3	«	«	71,1	24,6	100

Table 5.7. Chemical composition of sperrilyte (wt.%)

As	Ru	Rh	Pt	total
sperrilyte $PtAs_2$				
43,0	n.d.	n.d.	57,0	100
42,4	«	«	56,7	100
42,9	«	«	57,1	100
42,5	«	«	57,5	100
40,2	0,20	0,60	59,0	100
41,8	n.d.	0,10	58,1	100



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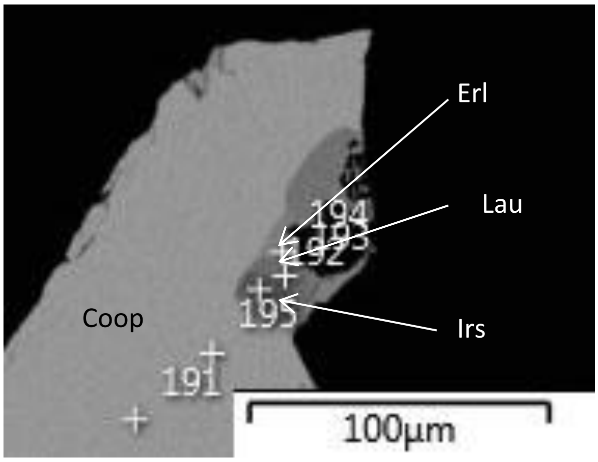

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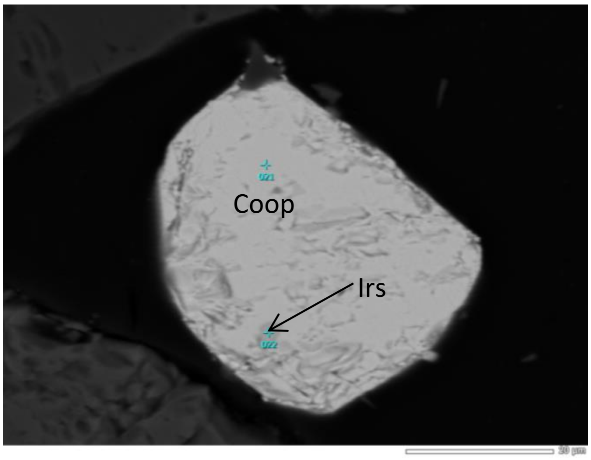

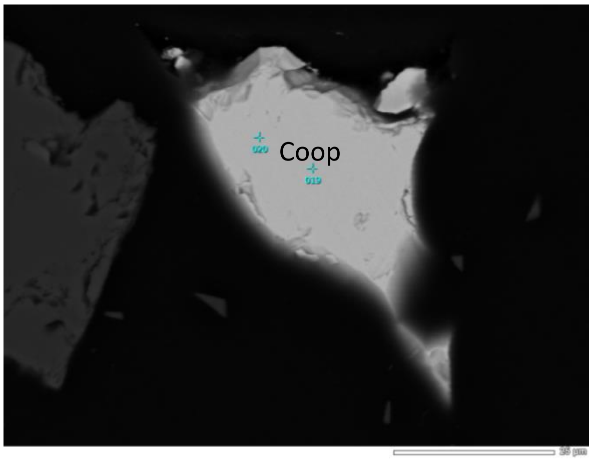

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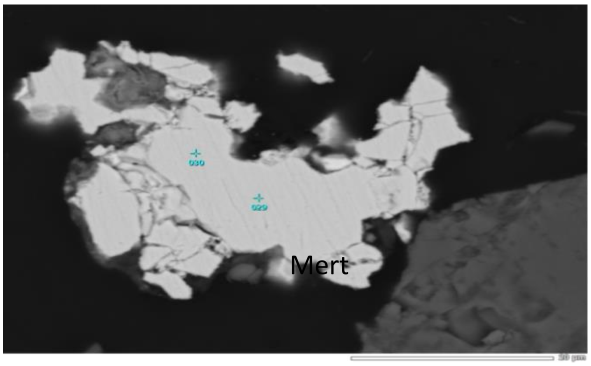
Fig. 5.22. Hypidiomorphic and xenimorphic shape of cooperite grains
A – inclusion of malanite in cooperite; B –Fig. 13A enlarged, intergrowth of irarsite with laurite-erlichmanite in cooprite; C – isometric inclusion of irarsite in cooperite; D – grain of cooperite free from inclusions. Gravity concentrate, X-ray image



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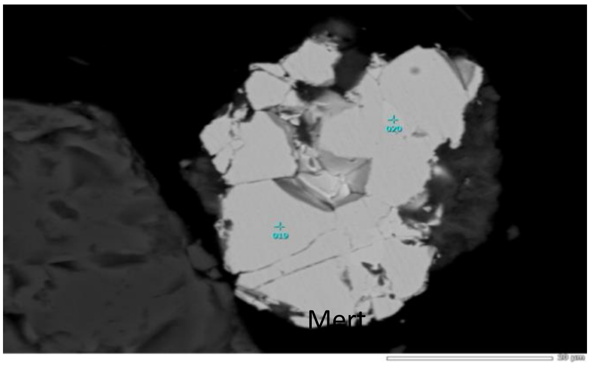

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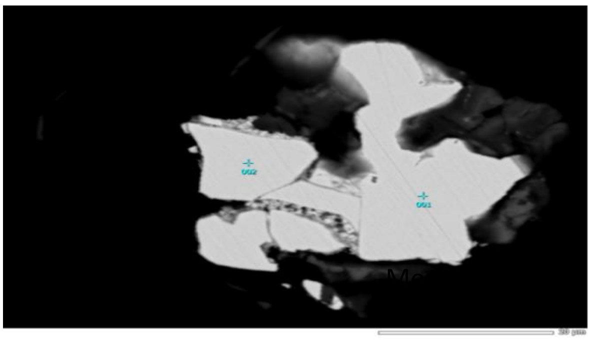

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Fig. 5.23. Aggregates of xenomorphic and «detrital» grains of mertieite-II. Gravity concentrate, X-ray image

Ferroplatinum is presented by rare xenomorphic grains ranging in size up to 30-35 microns. Characteristic feature of Pt-Fe alloys from apatite-magnetite-phlogopite-pyroxenite metasomatites is a constant impurity of copper - around 5 weight % (Fig. 5.25, Table 5.8), as well as Pt/Fe ratio tending to 2/1.

Table 5.8. Chemical composition of ferroplatinum (wt.%)

Fe	Ni	Cu	Ru	Rh	Pd	Pt	total
ferroplatinum (Pt,Fe,Cu) - $(Pt,Cu)_2Fe$?							
13,5	n.d.	5,29	n.d.	0,50	0,38	80,3	100
13,7	0,20	5,24	«	0,90	0,60	79,5	100
13,5	n.d.	4,96	0,1	0,80	0,52	80,2	100
13,5	«	4,48	n.d.	0,60	0,52	80,9	100

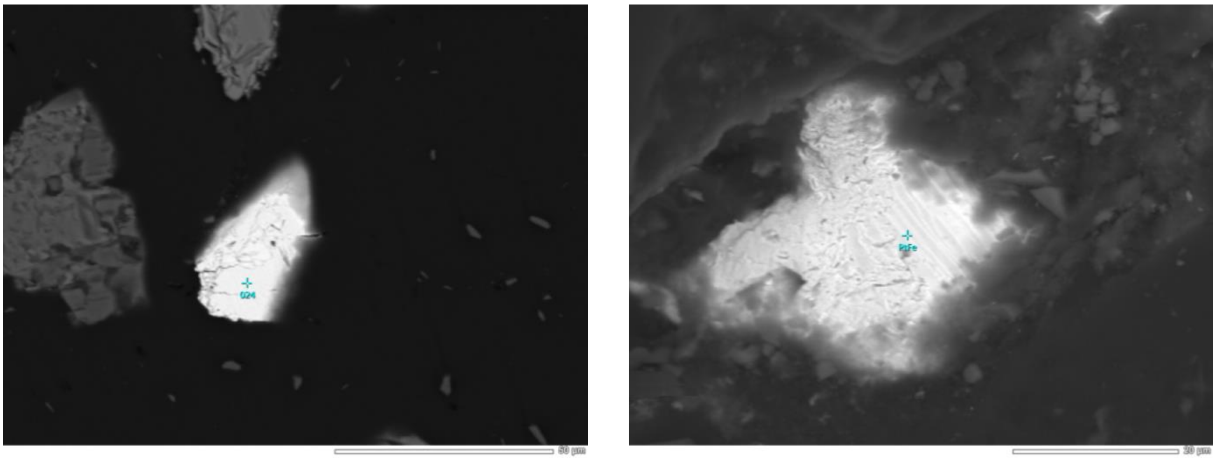

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Fig. 5.24. Morphology of segregations of Pt-Fe alloys. Gravity concentrate, X-ray image

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Field Trip 2: PGM placer deposits and their sources in the ultramafic and alkaline rocks of the concentrically zoned Kondyor massif, Far East, Russia

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Cover photo: the expedition camp of a pioneer of the placer deposit Kondyor – A.G. Mochalov, July 1979.

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