DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/98

Gold, PGE and sulfide phases of the precious metal mineralization of the Skaergaard intrusion

Part 19: Sample 90-24 1053

Nikolay S. Rudashevsky, Vladimir N. Rudashevsky
& Troels F. D. Nielsen

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DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

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Abstract

The report presents the results of mineralogical investigations of the sample 90-24 1053 collecting the interval between 1053 and 1054m in core 90-24 drilled through the PGE-Au mineralisation in the Skaergaaard intrusion. The sample originates from the Pd4 level, a small level 0.5m level of Pd enrichment 4.5-5 m above the main Pd5 peak. Assays give 720 ppb Pd, 24 ppb Au, and 20 ppb Pt for this interval.

The 980g sample was crushed in small portions using a shatter box with small cavities (200 ml) for short periods (0.3-0.5 min) and sieved to remove the fine fraction (sieve - 125 µm) after each crushing session. The residual coarse fraction >125 µm was re-crushed until the entire sample has attained the desired maximum grain size.

After complete crushing the material was sieved into the following fractions:: 1) <40, 2) 40-63, 3) 63-80, 4) 80-125 µm. All fractions were then subjected to wet magnetic separation to remove titanomagnetite and magnetite. All magnetic fractions proved not to contain precious metal grains.

All the non-magnetic grain size fractions were the processed through the computed controlled hydroseparator CNT-HS-11. Monolayer polished sections were produced the concentrates of every grain size fraction. These polished monolayer sections and one polished section of a chip from the core rock were investigated under the scanning electron microprobe.

Sample 90-24 1059 shows the characteristic reaction relationships between cumulus and intercumulus phases including: rims of olivine and anorthite at the boundaries between grains of Fe-Ti-oxides and clinopyroxene with exsolutions. In general, the sample is a "dry" rock. H_2O-bearing minerals are rarely found and only in very insignificant amounts in intergrowths with Cu-Fe-sulphides.

The HS-concentrates contain numerous sulphide grains identified as sulphide droplets. They are formed by one or more of the Cu-sulphides bornite, chalcosine and digenite. Several of these droplets and sulphide grains contain inclusions of PGMs.

A representative selection of PGMs in 78 grains was chosen for detailed studies. The dominating precious metal mineral is skaergaardite (Pd,Au,Pt)(Cu,Fe,Zn) (95.1 vol. %), followed by 8 minor minerals (~5 % of all PGMs of the sample) including nielsenite $(Pd,Au,Pt)Cu_3$ (2.0 vol. %), (Cu, Pd) alloy (0.9 vol. %), (Pd,Cu,Sn) alloy (0.5 vol. %), vasilite $(Pd,Cu)_{16}S_7$ (0.6 vol. %), kethconnite Pd_3Te (0.2 vol. %), unnamed $(Pd,Au)_3Cu$ (0.4 vol. %), unnamed $AuPdCu_2$ (0.3 vol. %) and zvyagintsevite Pd_3Pb (?) (<0.1 vol. %). The grain size of precious metal minerals (ECD) varies from 2 to 55 µm with an average of 23 µm.

Average composition of skaergaardite (analyses from 61 grains) is (wt. %):
Pd 60.4, Pt 0.8, Au 1.1, Cu 29.9, Fe 4.2, Zn 1.4, Sn 0.8, Te 0.5, Pb 0.4, Total 99.6; corresponding to the formula $(Pd_{0.98}Pt_{0.01}Au_{0.01})_{1.00}(Cu_{0.80}Fe_{0.13}Zn_{0.04}Sn_{0.01}Te_{0.01})_{0.99}$.

The estimated bulk composition of the sample (assays of whole rock in brackets) is (ppb): Pd 733 (720), Au 20 (24), Pt 11 (20). Pt is substituted into skaergaardite (~90 %) and in other precious metal minerals, such as nielsenite, (Cu,Pd) alloy and unnamed $AuPdCu_2$ (~10%). Au is substituted into skaergaardite (~70 %) and in Au-rich precious metal minerals (~30 %) - nielsenite, unnamed $(Pd,Au)_3Cu$ and $AuPdCu_2$.

The observations of the inter-grain relations suggest that all PGMs form single paragenesis. The sulphide droplets contain rare droplets of PGMs. The characteristic structure suggests the occurrence of two immiscible melts: 1) Cu-Fe sulphide melt and 2) metal melt enriched by Cu, Pd, Pt and Au and separated from sulphide melt.

Introduction

The report describes the mineralogy of sample 90-24 1053 from the Pd4b level in the “Platinova Reef” of the Skaergaard intrusion. The Pd4b level is a small anomaly 0.5m in width about 4.5m above the main Pd5 peak in core 90-24 (Andersen et al., 1998; Nielsen et al, 2005) The report is based on mineralogical information obtained from monolayer sections produced from concentrates obtained using the Hydroseparator CNT-HS-11 and a polished section of a chip of the gabbro. The polished sections were studied using electron microscopy and electron microprobe analysis (Camscan-4DV, Link AN-10 000). The report gives descriptions of grain characteristics, parageneses and the compositional variation within the identified groups of minerals in the host rock, the sulphide droplets, and the precious metal-bearing minerals and phases..

Sample 90-24, 1053

Sample 90-24 1053 collects the interval between 1053 and 1054m in BQ drill core # 90-24.The core was drilled with an azimuth of 0^o and an inclination of –70 from a location at 504 meters a.s.I, on the western slope of Basistoppen. The assays for the interval shows 720 ppb Pd, 24 ppb Au, and 20 ppb Pt (Watts, Griffis & McOuat, 1991). The core has previously been sampled for other purposes. The sample collects 1/3 of the diameter of the preserved core.

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003). The heavy mineral concentrates, enriched by precious metal minerals were obtained using the patented model of computer controlled Hydroseparator CNT-HS-11 and newly patented glass separation tube (GST) (Rudashevsky & Rudashevsky, 2006 and 2007). Also, one polished section was prepared from chip of the core rock. All the remaining material was crushed to <125 µm. After complete grinding, the sample was sieved with water into the following fractions:
-40 µm (301 g), 40-63 µm (137 g), 63-80 µm (74 g), 80-125 µm (284 g) and >125 µm (46 g), and then subjected to wet magnetitc separation to remove the titanomagnetite and magnetite. All magnetic fractions proved not to contain precious metal grains.

All the non-magnetic grain size fractions were the processed through the computed controlled hydroseparator CNT-HS-11. Monolayer polished sections were produced the concentrates of every grain size fraction. These polished monolayer sections and one polished section of a chip from the core rock were investigated under the scanning electron microprobe as described in Nielsen et al. (2003).

Results

Rock forming minerals and sulphide mineralogy

Silicates and FeTi-oxides

The silicates and FeTi-oxides related to sulphides are: 1) *plagioclase*, An_{46-51} (Table 1, analyses 1-3);2) *monoclinic ferrous pyroxene*, Mg# = 0.64-0.65 (Table 1, analyses 4, 5), 3) *orthorhombic ferrous pyroxene*, Mg# = 0.51-0.55 (Table 1, analyses 6, 7), 4) *fayalite*, Mg# = 0.47-0.50 (Table 1, analyses 8-10); Fe-Ti oxides including 5) *ilmenite* (Table 1, analyses 11-13) and 6) *titanomagnetite* (Table 1, analyses 14-16). Monoclinic and orthorhombic pyroxenes form classic exsolution textures (see Plate 1).

The Fe-Ti-oxides occur as aggregates of 1-3 mm, anhedral grains. They fill the space between grains of plagioclase and pyroxenes (Plate 1, #1-4). At the contact between pyroxenes and Fe-Ti-oxides these aggregates are rimmed by fayalite-rich olivine and anorthite –rich plagioclase (Plate 1, #1-4, 6), sometimes as symplectites (see, e.g., Holness et al., 2011).

The host gabbro of sample 90-24 1053 is a “dry” rock. Just few biotite grains ilmenite were identified in the studied polished section (Plate 1, #8). They occur in intergrowth with Cu-Fe sulphides. However, the volatile bearing minerals chamosite, ferrosaponite, hornblende, biotite and calcite were all found in the heavy mineral concentrates in and related to some of the sulphide globules (Plate 2, #5, 14, 17, 19), as well as with Cu-sulphides and PGMs (Plate 4, #2, 3).

Sulphides

In the polished section only a few sulphide grains of bornite, chalcosine and digenite were observed. They occure as droplets or irregular (10-30 µm) inclusions in pyroxene aggregates (Plate 1, #8) and in olivine grains (Plate 1, #7).

The nonmagnetic heavy concentrates are ilmenite-rich products (>95 %) enriched in grains of sulphides and PGMs (Fig.1). The sulphide grains are represented by up to 0.1 mm large droplet-like microglobules (Plate 2, #1-7; Plate 3, #1, 6: Plate 4, #1 etc) and .irregular aggregates (Plate 2, #8-19; Plate 3, #2-9. 13-20, 23-30 etc). The sulphide grains and aggregates are dominantly composed of bornite and chalcosine group minerals (see Plates 1, #7, 8; Plate 2). The volume ratio varies significantly from grain to grain (see Plate 2). Inside microglobules bornite and chalcosine group minerals form classic exsolution textures (Plate 2, #1, 3, 4, 6, 8-15 etc). The Cu-Fe sulphides bornine and chalcosine totally dominate the sulphide paragenesis. The compositions of bornite (Table 2, analyses 1, 4, 6), chalcosine (Table 2, analyses 5, 7) and digenite (Table 3, analyses 2, 3) are all near- stoikiometric.

One grain of cobalt pentlandite was also found the the concentrates (Plate 6, #65; Table 2, analysis 8). It is intergrown with nielsenite, (Cu,Pd) alloy and chalcosine. The cobalt pentlandite contains 31.2 % Co and 21.8 % Ni.

PGMs: recovery, grain size and relations to host rock

Recovery

The SEM studies of the polished section of the gabbro resulted in no finds of PGMs despite the concentration nearing 1g/t PGE. By contrast, the heavy mineral concentrates have yielded many PGM grains. For more detailed investigations 78 grains of a wide size range (from <40 μm up to 80-125 μm) were selected. In total, 9 different PGMs were identified in the sample 90-24 1053 and include:

1. *Skaergaardite* (Pd,Au,Pt)(Cu,Fe,Zn) - 72 grains,
2. *Nielsenite* $(Pd,Au,Pt)Cu_3$ –2 grains
3. *(Cu,Pd) alloy* - 1 grain
4. *Vasilite* $(Pd,Cu)_{16}S_7$ – 1 grain;
5. *(Pd,Cu,Sn) alloy* – 1 grain;
6. *Unnamed* $(Pd,Au)_3Cu$ – 1 grain;
7. *Unnamed* $(Au,Pt)PdCu_2$ – 2 grains;
8. *Keithconnite* Pd_3Te – 12 inclusions in 3 grains,
9. *Zvyagintsevite* Pd_3Pb – inclusion in 1 grain.

The volumetric proportions of these minerals and phases are calculated from the area of grains (seeTable 3, 4 and Fig. 2).

Grain size

The grain size is measured by the effective diameter of the grains (ECD) using the "imageJ" ® software. It varies from 2 to 55 μm with an average of 23 μm (Table 3; Fig. 3).

The histogram of the grain sizes (Fig. 3) is shown a lognormal distribution for the statistical selection (n=78). According to the histogram, the size of grains of precious metal minerals is distributed as follows:

Grain size, μm	Number of grains
0-10	14
10-20	21
20-30	24
30-40	11
40-50	6
50-60	2

The SEIs (scanning electron images) show that majority of PGM grains are well preserved and have kept their primary shape and size (Plates 3-6). Grains have not been broken during production of the concentrates. The largest proportion of PGM grains is concentrated in the <40 μm fraction.

Petrographic observations

The almost perfect separation of accessory minerals has been achieved by gentle crushing/disintegration of the studied sample. The method of disintegration allows in general preservation of primary grain size and inter-grain relationships. The concentrates provide the information needed for the reconstruction of the primary shapes and sizes of accessory minerals, together the paragenesises and the relationships with rock-forming minerals of the host rock.

In the concentrates of sample 90-24 1053 the precious metal mineral grains (n=78) occur in the following mineral associations (Fig. 4; Table 5):

Table 5.

Associations of PGM grains in the heavy mineral concentrates of sample 90-24, 1053.

Association	PGM- grains, vol. %
L	30.9
bms-L	37.8
bms	27.5
sag	2.6
ag-L	1.2

L - completely liberated (free) particles; **bms-L** - liberated particles with <10 % attached base metal sulphides; **bms** - intergrowths with base metal sulphides (bornite, chalcosine, digenite, cobalt pentlandite); **sag** - sulphide and gangue (ilmenie, plagioclase, hornblende and chlorite) attached to PGMs; **ag-L** – precious metal minerals attached to gangue, but <10% gangue (ilmenite).

Liberated PGM grains amounts to 30.9% in the heavy mineral concentrates iHowever, grains attached to **bms** (**bms**+**bms-L**+**sag**+**sag-L** associations) dominate and constitute 67.9% of the precious metal mineral paragenesis (see Fig 4,b), whereas only 1.2% of the PGMs are attached to gangue (**ag-L** associations).

Based on SEIs, precious metal minerals in the heavy mineral concentrates divide into different groups:

1. skaergaardite grains-intergrowths with base metal sulphides (**bms, bms-L**), - (Plate 3);
2. skaergaardite grains-intergrowths with gangue or with gangue and base metal sulphides (**sag,** and **ag-L**) – (Plate 4);
3. completely liberated skaergaardite grains (**L**) – (Plate 5).
4. grains containing precious metal minerals but other than skaergaardite (Plate 6).

Description and composition of PGMs

Skaergaardite (Pd,Au,Pt)(Cu,Fe,Zn,Sn,Te)

Description
Skaergaardite (Rudashevsky et al., 2004) is the dominant Pd mineral in heavy mineral concentrates of the sample 90-24 1053 (95.1 vol.% of all precious metal minerals, see Table 4). It is found in the following forms:

1. liberated (free) grains: **L** (Plate 5);
2. in intergrowths with the base metal sulphides(bornite, chalcosine, digenite: **bms** (Plate 3, #1-9. 15-20, 23-32, 38; Plate 6, #2); **bms-L** (Plate 3, #10-14, 21, 22, 33-37, 39-42; Plate 6, #1, 4);
3. in intergrowths with sulphide and gangue including plagioclase, chlorite, hornblende, ilmenite: **sag** (Plate 4, #1-3); **ag-L** (Plate 4, #4)
4. in intergrowths with other precious metal minerals including keithconnite (Plate 6, #2, 4), (Pd,Cu,Sn) (Plate 6, #9), zvyagintsevite (plate 6, #1) and unnamed $AuPdCu_2$ (Plate 6, #7).

Besides the liberated grainsskaergaardite also shows strong association with base metal sulphides (see Plate 3; Plate 4, #1-3; Plate 6, #1, 2, 4). Skaergaardite-bearing sulphide grains occur as droplet-like (Plate 3, #6, 9, 20; Plate 4, #1) aggregates and .irregular-shaped (Plate 3, #1-5, 7, 8, 16-19, 23, 25-30 etc). Usually skaergaardite grains are localized at the margins of the sulphide globules (Plate 3, #1-15, 18-29 etc).

Skaergaardite grains occur as:

1. isometric droplet-like grains with rounded outlines (Plate 3, #6. 7. 9-15, 42; Plate 4, #2; Plate 5, # 1-3, 5-7; Plate 6, #1, 2, 9);
2. euhedral or subhedral grains (Plate 3, #1, 2, 8, 16-26, 32-37; Plate 4, #4; Plate 5, #4, 8; Plate 6 , #4);
3. irregular grains and aggregates (Plate 3, #3-5, 27-31, 38-41; Plate 4, # 1, 3; Plate 5, #9-20 etc).

The recorded grain size of skaergaardite is between 2 and 55 μm with an average of 23 μm (Table 4).

Mineral chemistry

The composition of skaergaardite is constrained by 61 analyses in 61 grains (Table 6). The average composition of skaergaardite (Table 6, analysis 62) is (wt. %): Pd 60,4; Pt 0.8, Au 1.1, Cu 29.9, Fe 4.2, Zn 1.4, Sn 0.8, Te 0.5, Pb 0.4, Total 99.6. The composition corresponds to the followingformula:

$$(Pd_{0.98}Pt_{0.01}Au_{0.01})_{1.00}(Cu_{0.80}Fe_{0.13}Zn_{0.04}Sn_{0.01}Te_{0.01})_{0.99}.$$

Typical substitutions into skaergaardite are Pt up to 9.2 % (Table 6, analysis 42), Au up to 13.0 % (Table 6, analysis 1), Fe up to 6.9 % (Table 6, analysis 54), Zn up to 2.9 % (Table 6, analysis 60), Sn up to 18.9 % (Table 6, analysis 47), Te up to 4.0 % (Table 6, analysis 2), and Pb up to 2.4 % (Table 6, analysis 13).

The Pt and Au concentrations in the 61 analyses of skaergaardite are distributed as follows (see also Fig. 5):

Interval, Pt wt %	Number of analyses - Pt	Interval, Au wt %	Number of analyses -Au
0-1	45	0-1	39
1-3	12	1-3	16
3-5	2	2-3	4
5-7	0	5-7	0
7-9	1	7-9	0
9-11	1	9-11	0
		11-13	2

Nielsenite (Pd,Au,Pt)(Cu,Fe)$_3$

The new mineral Nielsenite $PdCu_3$ (2004-046) was discovered by the authors of this report in Skaergaard ores. It has been recently approved by CNM MMA.

Two grains of nielsenite (McDonald et al., 2008) were found in heavy minerals concentrates of sample 90-24 1053 and constitute 2.0 vol% of the precious metal mineral paragenesis. (see Table 4). Nielsenite is associated with (Cu,Pd) alloy and the base metal sulphides chalcosine, bornite and cobalt pentlandite (Plate 6, #5, 6). The grain size of nielsenite is 8-31 μm, with an average of 20 μm. The composition of nielsenite is near-stoikiometric (Pd,Au,Pt)(Cu,Fe)$_3$ (Table 7, analyses 2, 3). Characteristic substitutions into nielsenite are Au (2.5-15.0 %), Pt (1.1-9.5 %) and Fe (0.4-1.2 %)

(Cu,Pd) alloy

As opposed to skaergaardite and nielsenite, (Cu,Pd) alloy is non-stoikiometric. One grain of this alloy (0.9 vol % of precious metal minerals) was found in the concentrates (see Table 4). It is associated with nielsenite, chalcosine, bornite and cobalt pentlandite (Plate 6, #5). The size of this grain is 22 µm. The composition of the (Cu,Pd) alloy is given in Table 7 (analyses 1). Substitutions in (Cu,Pd) alloy are Pt (1.2 wt.%) Au (1.2 wt.%), Fe (1.9 wt. %) and Zn (1.8 wt. %).

Rare PGMs

Other 6 precious metal minerals, that were found in the heavy mineral concentrates and constitute all together 2 vol.% of the precious metal mineral paragenesis. They include: vasilite, (Pd,Cu,Sn) alloy, unnamed $(Pd,Au)_3Cu$, unnamed $(Au,Pt)PdCu_2$, keithconnite and zvyagintsevite.

Vasilite $(Pd,Cu)_{16}S_7$

Vasilite $(Pd,Cu)_{16}S_7$ is found in just one liberated grain in the concentrates (Plate 6, #10). It has an irregular shape and a size of 18 µm. Its composition corresponds to the stoikiometric formulae $(Pd,Cu)_{16}S_7$ (Table 7, analysis 10). It represents ~0.6 vol. % of the precious metal mineral paragenesis of sample 90-24 1059 (Table 4).

(Pd,Cu,Sn) alloy

(Pd,Cu,Sn) alloy is in the concentrates found (Table 7, analysis 5) in just one droplet-like liberated grain in association with skaergaardite (Plate 6, #9). The size of the grain is 16 µm and it represents ~0.5 vol. % of precious metal mineral paragenesis (Table 5).

Unnamed $(Pd,Au)_3Cu$

A mineral with composition $(Pd,Au)_3Cu$ is identified (Table 7, analysis 4) in just one irregular shape liberated grain in the concentrates of sample 90-24 1053 (Plate 6, #11). The size of the grain is 15 µm and it represents ~0.4 vol. % of precious metal mineral paragenesis (Table 4).

Besides of Pd and Cu, $(Pd,Au)_3Cu$ contains 54 wt. % Au and shows some substitution of Fe (1.3 wt. %). Its composition corresponds to the stoikiometric formula $(Pd,Au)_3(Cu,Fe)$ Unnamed $(Pd,Au)_3Cu$ is a Pd analogue of Au_3Cu (bogdanovite?).

Unnamed $(Au,Pt)PdCu_2$

A mineral with composition $(Au,Pt)PdCu_2$ is found (Table 7, analysis 8, 9) in two grains in the heavy mineral concentrates of sample 90-24 1053. It is associated with skaergaardite, bornite and chalcosine (Plate 6, #7, 8). The size of both $AuPdCu_2$ grains is 9 µm and they represent ~0.3 vol. % of the precious metal mineral paragenesis of the sample 90-24 1053 (see Table 4).

Besides Au, Pd and Cu this unnamed mineral contains 2.1-6.7 wt. % Pt and admixture of Fe (0.9-1.8 wt. %). Its composition corresponds to the stoikiometric formulae $(Au,Pt)Pd(Cu,Fe)_2$. The unnamed mineral $(Au,Pt)Pd(Cu,Fe)_2$ can be seen as a Pd-rich variety of tetra-auricupride or an Au-rich variety of skaergaardite, but may alternatively be a new mineral phase, a question that only can be solved using x-ray identification.

Keithconnite Pd_3Te

Keithconnite Pd_3Te is identified as small 1-8 µm (avr. 3 µm) inclusions in two skaergaardite grains and in one bornite and chalcosine sulphide globule (Plate 6, # 2-4). It represents 0.2 vol. % of all precious metal mineral paragenesis of sample 90-24 1053 (see Table 4). Compositions are given in table 7, analyses 6, 7. Characteristic substitutions in keithconnite are: Pt (1.2 wt.%), Au (1.8 wt.%), Fe (1.0 wt. %), Cu (0,7-3.3 wt. %), Sn (0.8 wt. %) and Pb (0.7-3.4 wt. %).

Zvyagintsevite Pd_3Pb?

Zvyagintsevite Pd_3Pb is found under the SEM as very small (~2 µm) inclusion in one skaergaardite grain (Plate 6, #1). Zvyagintsevite constitutes less than 0.1 vol. % of all the precious metal minerals in sample 90-24 1053 (see Table 4).

Bulk composition of PGMs of the sample 90-24 1053

The relative concentrations of Pd, Au and Pt of the sample 90-24 1053 can be calculated from the total concentration of precious metal, the observed recovery, the modal proportions, and the compositions of the minerals and phases (Tables 4, 6, 7). The estimated bulk composition of the sample (assays of whole rock in brackets) is (ppb): Pd 733 (720), Au 20 (24), Pt 11 (20). Pt is hosted in skaergaardite (~90 %) and in other precious metal minerals: nielsenite, (Cu,Pd) alloy and unnamed $AuPdCu_2$ (~10%). Au is hosted in skaergaardite (~70 %) and in Au-rich precious metal minerals (~30 %): nielsenite, unnamed $(Pd,Au)_3Cu$ and $AuPdCu_2$.

Discussion

The PGM-paragenesis

The data shows that skaergaardite is the totally dominant PGM in the studied sample. Skaergaardite shows a wide compositional range (Table 6). All the observations and the inter-grain relations (Plates 3-6) suggest that all precious metal minerals are parts of a single paragenesis.

Order of crystallization

The Cu-Fe sulphides and precious metal minerals are synchronous and crystallized later than most of the rock-forming minerals plagioclase, clinopyroxene, orthopyroxene, ilmenite and titanomagnetite.

The characteristic droplet shape of both the PGMs and host sulphides suggest that they represent two immiscible melts: 1) a Cu-Fe sulphide melt and 2) a metal melt enriched in Pd, Cu, Pt and Au and separated from the Cu-Fe sulphide melt. The observation is in agreement with the results of the experimental incvestigation of the Cu-Pd-S system (Karup-Møller & Makovicky, 1999).

The residual sulphide-metal melt phase seems to have been enriched by fluid components (H_2O, CO_2 etc). That is suggested by the characteristic associations of PGE- and Au-bearing aggregates of Cu-Fe sulphides with H_2O- and CO_2-bearing the minerals chamosite, ferrosaponite, biotite, hornblende, calcite, etc.

Summary

1. 78 PGM-grains were identified in the heavy mineral concentrates of the sample 90-24 1053. The concentrates og the 0.98kg sample were obtained using the patented hydroseparator CNT-HS-11.

2. The totally dominant (95.1 vol.%) precious metal mineral is skaergaardite (Pd,Pt,Au)(Cu,Fe,Zn,Sn,Te). Besides skaergaardite at least 8 other PGMs (totalling ~ 5 vol. %) were identified: nielsenite $(Pd,Au,Pt)Cu_3$ (2.0 vol.%), (Cu,Pd) alloy (0.9 vol.%), vasilite $(Pd,Cu)_{16}S_7$ (0.6 vol.%), (Pd,Cu,Sn) alloy (0.5 vol.%), unnamed $(Pd,Au)_3Cu$ (0.4 vol.%), unnamed $AuPdCu_2$ (0.3 vol.%), keithconnite Pd_3Te (0.2 vol.%) and zvyagintsevite Pd_3Pb? (0.1 vol.%).

3. The estimated bulk composition of the sample (assays of whole rock in brackets) is the f (ppb): Pd 733 (720), Au 20 (24), Pt 11 (20). Pt concentrates in skaergaardite (~90 %) and in other precious metal minerals including nielsenite, (Cu,Pd) alloy and unnamed $AuPdCu_2$ (~10%). Au is in skaergaardite (~70 %) and in Au-rich precious metal minerals (~30 %) - nielsenite, unnamed $(Pd,Au)_3Cu$ and $AuPdCu_2$.

4. The sulphide droplets contain droplets of PGMs. The characteristic texture suggests the occurrence of two immiscible melts: 1) Cu-Fe sulphide melt and 2) metal melt enriched by Cu, Pd, Pt and Au and separated from the sulphide melt.

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TABLES

Table 1. Compositions of silicates and FeTi-oxides of sample 90-24 1053

	plagioclase			clinopyroxene		orthopyroxene		olivine			ilmenite			titanomagnetite		
Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
wt%																
SiO_2	56.8	56.0	55.5	51.0	51.0	51.5	50.5	35.0	34.9	34.2	-	-	-	-	-	-
TiO_2	-	-	-	0.3	0.2	0.4	-	-	-	-	51.5	51.5	51.4	11.3	13.4	14.5
Al_2O_3	26.9	27.3	27.8	1.5	1.0	0.4	0.4	-	-	-	-	-	-	7.3	3.6	3.7
V_2O_3	-	-	-	-	-	-	-	-	-	-	0.4	0.6	0.2	1.5	1.7	1.7
Fe_2O_3	-	-	-	-	-	-	-	-	-	-	2.7	2.8	3.4	38.1	37.5	35.5
FeO	-	-	-	12.8	13.1	27.1	29.4	42.5	41.3	43.1	42.6	42.9	41.9	40.3	42.2	43.7
MnO	-	-	-	0.3	0.2	0.5	0.6	0.7	0.5	0.4	0.4	0.4	0.5	0.3	0.3	0.6
MgO	-	-	-	13.2	12.9	18.7	17.2	22.7	23.3	21.5	1.7	1.7	2.2	1.0	1.1	0.7
CaO	9.7	9.3	10.1	21.0	20.8	1.4	1.1	-	-	-	-	-	-	-	-	-
Na_2O	5.9	6.6	5.4	-	-	-	-	-	-	-	-	-	-	-	-	-
K_2O	0.2	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	99.5	99.5	99.1	100.1	99.2	100.0	99.2	100.8	100.0	99.1	99.3	99.9	99.6	99.6	99.8	100.2
Atomic proportions																
Si	2.55	2.53	2.52	1.94	1.95	1.97	1.97	1.00	1.00	1.00	-	-	-	-	-	-
Ti	-	-	-	0.01	0.01	0.01	-	-	-	-	0.97	0.97	0.97	0.30	0.37	0.4
Al	1.43	1.46	1.49	0.07	0.05	0.02	0.02	-	-	-	-	-	-	0.30	0.16	0.16
V	-	-	-	-	-	-	-	-	-	-	0.01	0.01	-	0.04	0.05	0.05
Fe3+	-	-	-	-	-	-	-	-	-	-	0.05	0.05	0.06	1.05	1.04	0.98
Fe2+	-	-	-	0.41	0.42	0.87	0.96	1.02	0.99	1.05	0.90	0.90	0.87	1.24	1.31	1.35
Mn	-	-	-	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Mg				0.75	0.74	1.07	1.00	0.97	0.99	0.94	0.07	0.06	0.08	0.05	0.06	0.04
Ca	0.47	0.45	0.49	0.85	0.85	0.06	0.05	-	-	-	-	-	-	-	-	-
Na	0.52	0.57	0.47	-	-	-	-	-	-	-	-	-	-	-	-	-
K	0.01	0.02	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
O-basis	8	8	8	6	6	6	6	4	4	4	3	3	3	4	4	4
An%	0.47	0.44	0.51	-	-	-	-	-	-	-	-	-	-	-	-	-
mg#	-	-	-	0.65	0.64	0.55	0.51	0.49	0.50	0.47	-	-	-	-	-	-

Table 2. Compositions of sulphides in PGM-bearing globules of the heavy mineral concentrates from sample 90-24 1053

				Analysis (wt%)						*Proportions*					
An	**Grain**	**Association**	**Mineral**	**Cu**	**Fe**	**Ni**	**Co**	**S**	**Total**	**Cu**	**Fe**	**Ni**	**Co**	**S**	**Total**
1	40 gr2	sk+kth+ch+bn	bn	62,4	11,1	-	-	25,7	99,2	*4,95*	*1,00*	-	-	*4,05*	*10*
2	40 gr40a	dg	dg	77,1	0,9	-	-	21,2	99,2	*8,97*	*0,13*	-	-	*4,90*	*14*
3	80 gr10a	dg+bn	dg	77,5	0,8	-	-	21,6	99,9	*8,95*	*0,11*	-	-	*4,94*	*14*
4	80 gr10a	dg+bn	bn	63,3	10,3	-	-	26,3	99,9	*4,98*	*0,92*	-	-	*4,09*	*10*
5	80 gr2a	ch+bn	ch	78,6	0,8	-	-	20,4	99,8	*1,97*	*0,02*	-	-	*1,01*	*3*
6	80 gr2a	ch+bn	bn	63,2	11,3	-	-	25,4	99,9	*5,00*	*1,02*	-	-	*3,98*	*10*
7	125 gr3a	ch+bn	ch	78,2	0,7	-	-	20,0	98,9	*1,98*	*0,02*	-	-	*1,00*	*3*
8	63 gr14	nls+(Cu,Pd)+ch+bn+copn	copn	-	13,8	21,8	31,2	32,2	99,0	-	*1,83*	*2,96*	*4,22*	*8,00*	*17*

Abbreviations: sk: skaergaardite; kth: keithconnite; dg: digenite; nls: nielsenite; (Cu,Pd): alloy; bn:bornite; ch: chalcosine;copn: cobalt pentlandite.

Table 3. Grain sizes of precious metal minerals and phases in the heavy mineral concentrates of sample 90-24 1053

Abbreviations: Pd3Cu: unnamed mineral; sk: skaergaardite; (Pd,Cu,Sn): alloy; kth: keithconnite; zv: zvyagintsevite; nls: nielsenite; AuPdCu2; unnamed mineral; (Cu,Pd): alloy; ch: chalcosine; bn: bornite; copn: cobalt pentlandite; pl: plagioclase; hb: hornblende; chl: chlorite and ilm: ilmenite.

analysis	Grain #	host/ association	Assoc.type	Mineral	Note	Area µm^2	ECD, µm
1	40-10	Pd3Cu	L	Pd3Cu		168	15
2	40-11	sk+(Pd,Cu,Sn)	L	Total		872	33
3	40-11	sk+(Pd,Cu,Sn)	L	(Pd,Cu,Sn)		200	16
4	40-11	sk+(Pd,Cu,Sn)	L	sk		672	29
5	40-12	sk	L	sk		232	17
6	40-13	sk+ch	bms-L	sk		271	19
7	40-14	sk+bn	bms-L	sk		311	20
8	40-15	sk	L	sk		539	26
9	40-16	sk+ch	bms-L	sk		876	33
10	40-17	sk+bn	bms-L	sk		504	25
11	40-18	sk+ilm	ag-L	sk		479	25
12	40-19	sk+bn+ch	bms	sk		259	18
13	40-1	sk+bn+ch	bms	sk		256	18
14	40-20	sk	L	sk		262	18
15	40-21	sk	L	sk		526	26
16	40-22	sk+bn	bms-L	sk		638	29
17	40-23	sk	L	sk		985	35
18	40-24	sk+bn+ch	bms-L	sk		540	26
19	40-25	sk+bn	bms	sk		441	24
20	40-26	sk	L	sk		331	21
21	40-27	sk+bn	bms-L	sk		846	33
22	40-28	sk	L	sk		508	25
23	40-29	sk+bn	bms	sk		60	9
24	40-2	sk+kth+bn	bms	Total		921	34
25	40-2	sk+kth+bn	bms	kth	4 grains	46	8
26	40-2	sk+kth+bn	bms	sk		875	33
27	40-30	sk	L	sk		489	25
28	40-31	sk+bn	bms-L	sk		929	34
29	40-32	sk+ch	bms	sk		141	13
30	40-33	sk	L	sk		660	29
31	40-34	sk	L	sk		178	15
32	40-35	sk+zv+bn	bms-L	Total		457	24
33	40-35	sk+zv+bn	bms-L	zv		2	2
34	40-35	sk+zv+bn	bms-L	sk		455	24
35	40-36	sk+bn	bms-L	sk		960	35
36	40-37	sk+bn	bms-L	sk		1394	42
37	40-38	sk+bn+ch	bms	sk		191	16
38	40-39	sk+bn	bms-L	sk		1335	41
39	40-3	sk	L	sk		220	17
40	40-40	sk+bn	bms	sk		739	31
41	40-5	sk+bn	bms	sk		532	26
42	40-6	sk	L	sk		433	23
43	40-7	sk+bn	bms	sk		324	20
44	40-8	sk+ch+bn	bms	sk		194	16
45	40-41	sk	L	sk		430	23
46	40-42	sk+ch+bn	bms	sk		148	14
47	40-43	sk+bn+ch	bms	sk		359	21
48	40-44	sk+bn+hb	sag	sk		918	34
49	40-45	sk+kth+bn	bms-L	Total		317	20
50	40-45	sk+kth+bn	bms-L	kth		40	7
51	40-45	sk+kth+bn	bms-L	sk		277	19

Table 3, 24-1053 continued

analysis	Grain #	host/ association	Assoc.type	Mineral	Note	Area μm^2	ECD, μm
52	40-46	sk	L	sk		540	26
53	40-48	vs	L	vs		253	18
54	40-49	sk+$AuPdCu_2$	L	Total		136	13
55	40-49	sk+$AuPdCu_2$	L	$AuPdCu_2$		59	9
56	40-49	sk+$AuPdCu_2$	L	sk		77	10
57	40-50	sk+bn	bms	sk		409	23
58	40-51	sk	L	sk		548	26
59	63-10	sk+bn+ch	bms	sk		20	5
60	63-11	sk	L	sk		625	28
61	63-12	sk	L	sk		149	14
62	63-13	sk+bn+ch	bms	sk		4	2
63	63-14	nls+(Cu,Pd)+ch+bn+copn	bms	Total		1130	38
64	63-14	nls+(Cu,Pd)+ch+bn+copn	bms	nls		753	31
65	63-14	nls+(Cu,Pd)+ch+bn+copn	bms	(Cu,Pd)		377	22
66	63-15	sk+bn+ch	bms	sk		749	31
67	63-1	sk+ch+bn	bms	sk		13	4
68	63-2	sk+bn	bms-L	sk		1812	48
69	63-3	sk+bn+ch	bms	sk		20	5
70	63-4	sk+ch	bms	sk		274	19
71	63-5	sk	L	sk		1879	49
72	63-6	sk+bn+ch	bms-L	sk		1671	46
73	63-7	sk	L	sk		1755	47
74	63-8	kth+bn+ch	bms	kth		2	2
75	63-9	sk+bn+ch	bms	sk		515	26
76	63-15-2	sk+bn+ch+chl	sag	sk		78	10
77	63-16	sk+ch	bms	sk		296	19
78	63-17	sk+bn+ch	bms	sk		79	10
79	63-18	sk+bn+pl	sag	sk		45	8
80	63-18	sk+bn+pl	sag	sk		14	4
81	63-19	sk+bn	bms	sk		103	11
82	80-1	sk+bn+ch	bms	sk		2408	55
83	80-2	sk+bn+ch	bms	sk		8	3
84	80-3	AuPdCu2+bn+ch	bms	AuPdCu2		69	9
85	80-4	nls+bn+ch	bms	nls		50	8
86	125-1	sk+bn+ch	bms-L	sk		2110	52
87	125-2	sk+bn	bms	sk		648	29
88	125-3	sk+bn+ch	bms-L	sk		613	28

Table 4. PGMs in the heavy mineral concentrates of sample 90-24 1053

Analysis #	Mineral	General formula	Number of grains	Grain size, mm			Vol. %
				min	max	average	
1	Skaergaardite	(Pd,Pt,Au)(Cu,Fe,Zn)	72	2	55	24	95.1
2	Nielsenite	$(Pd,Au,Pt)(Cu,Fe)_3$	2	8	31	20	2
3	(Cu,Pd) alloy	(Cu,Pd,Au,Pt)	1	-	-	22	0.9
4	Vasilite	$(Pd,Cu)_{16}S_7$	1	-	-	18	0.6
1	(Cu,Pd,Sn) alloy	(Cu,Pd,Sn)	1	-	-	16	0.5
6	Unnamed	$(Pd,Au)_3(Cu,Fe)$	1	-	-	15	0.4
7	Unnamed	$(Au,Pt)PdCu_2$	2	9	9	9	0.3
8	Keithconnite	$Pd_3(Te,Sn,Pb)$	12 in 3	1	8	3	0.2
9	Zviagintsevite	Pd_3Pb?	1	-	-	2	<0.1
	Total						100

Table 5

Enclosed in the text

Table 6. **Composition of skaergaardite in PGM-grains of the heavy mineral concentrates from sample 90-24 1053**

Abbreviations: sk: skaergaardite; kth: keithconnite; (Pd,Cu,Sn): alloy; $AuPdCu_2$: unnamed mineral; bn: bornite; ch: chalcosine; hb: hornblende and chl: chlorite

			Analysis (wt%)										***Proportions***									
An	**Grain**	**Association**	**Pd**	**Pt**	**Au**	**Cu**	**Fe**	**Zn**	**Sn**	**Te**	**Pb**	**Total**	***Pd***	***Pt***	***Au***	***Cu***	***Fe***	***Zn***	***Sn***	***Te***	***Pb***	***Total***
1	40 gr1	sk+bn+ch	47.8	3.8	13.0	31.0	1.7	0.0	0.0	2.3	0.0	99.5	*0.84*	*0.04*	*0.12*	*0.91*	*0.05*	*0.07*	*0.00*	*0.03*	*0.00*	*2.00*
2	40 gr2	sk+kth+bn+ch	57.1	2.7	2.6	29.5	1.6	1.1	0.0	4.0	0.0	98.6	*0.97*	*0.02*	*0.02*	*0.84*	*0.05*	*0.03*	*0.00*	*0.06*	*0.00*	*2.00*
3	40 gr3	sk	59.3	0.0	0.0	36.0	3.4	0.8	0.0	0.0	0.0	99.5	*0.93*	*0.00*	*0.00*	*0.95*	*0.10*	*0.02*	*0.00*	*0.00*	*0.00*	*2.00*
4	40 gr4	sk	63.4	0.0	0.0	29.5	5.1	1.2	0.0	0.0	1.0	100.2	*1.01*	*0.00*	*0.00*	*0.79*	*0.16*	*0.03*	*0.00*	*0.00*	*0.01*	*2.00*
5	40 gr5	sk+bn	62.4	0.0	0.0	31.1	5.9	0.0	0.0	0.0	0.0	99.4	*0.99*	*0.00*	*0.00*	*0.83*	*0.18*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
6	40 gr6	sk	62.2	1.2	0.0	30.6	5.2	0.0	0.0	0.7	0.0	100.0	*1.00*	*0.01*	*0.00*	*0.82*	*0.16*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*
7	40 gr7	sk+bn	62.0	0.0	0.0	29.9	5.2	1.2	0.0	0.0	0.0	99.0	*1.00*	*0.00*	*0.00*	*0.81*	*0.16*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
8	40 gr8	sk+ch+bn	57.5	0.0	2.3	34.1	2.7	2.5	0.0	0.0	0.0	99.1	*0.92*	*0.00*	*0.02*	*0.91*	*0.08*	*0.06*	*0.00*	*0.00*	*0.00*	*2.00*
9	40 gr9	sk	63.4	0.0	0.0	30.5	5.0	1.4	0.0	0.0	0.0	100.3	*1.00*	*0.00*	*0.00*	*0.81*	*0.15*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
10	40.11	sk+(Pd,Cu,Sn)	60.2	0.0	0.0	30.7	0.7	0.0	7.2	0.0	1.0	99.8	*1.00*	*0.00*	*0.00*	*0.86*	*0.02*	*0.00*	*0.11*	*0.00*	*0.01*	*2.00*
11	40 gr12	sk	61.4	0.0	1.5	29.4	4.5	1.5	0.0	1.2	0.0	99.5	*1.00*	*0.00*	*0.01*	*0.80*	*0.14*	*0.04*	*0.00*	*0.02*	*0.00*	*2.00*
12	40 gr13	sk+ch	61.1	0.0	1.0	29.8	4.5	1.9	0.0	1.2	0.0	99.5	*0.98*	*0.00*	*0.01*	*0.80*	*0.14*	*0.05*	*0.00*	*0.02*	*0.00*	*2.00*
13	40 gr14	sk+bn	58.9	1.0	1.8	29.0	2.4	0.8	3.0	0.6	2.4	99.9	*0.99*	*0.01*	*0.02*	*0.81*	*0.08*	*0.02*	*0.05*	*0.01*	*0.02*	*2.00*
14	40 gr15	sk	61.3	1.0	1.4	28.6	4.0	2.8	0.0	0.8	0.0	99.9	*0.99*	*0.01*	*0.01*	*0.78*	*0.12*	*0.08*	*0.00*	*0.01*	*0.00*	*2.00*
15	40 gr16	sk+ch	59.8	1.0	1.4	30.1	2.9	1.7	1.2	0.0	1.6	99.7	*0.98*	*0.01*	*0.01*	*0.83*	*0.09*	*0.05*	*0.02*	*0.00*	*0.01*	*2.00*
16	40 gr17	sk+bn	61.3	0.0	0.0	29.7	1.8	0.6	4.1	0.0	1.9	99.4	*1.02*	*0.00*	*0.00*	*0.83*	*0.06*	*0.02*	*0.06*	*0.00*	*0.02*	*2.00*
17	40 gr18	sk+ilm	62.2	0.0	0.0	30.0	5.4	1.0	0.0	0.0	0.0	98.6	*1.00*	*0.00*	*0.00*	*0.81*	*0.16*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
18	40 gr20	sk	55.1	7.5	1.0	28.9	6.2	0.0	0.0	0.0	1.2	99.9	*0.91*	*0.07*	*0.01*	*0.80*	*0.20*	*0.00*	*0.00*	*0.00*	*0.01*	*2.00*
19	40 gr21	sk	61.4	0.0	0.0	29.7	4.7	1.8	0.0	0.9	0.0	98.5	*0.99*	*0.00*	*0.00*	*0.80*	*0.15*	*0.05*	*0.00*	*0.01*	*0.00*	*2.00*
20	40 gr22	sk+bn	63.3	0.0	0.0	30.0	5.5	1.4	0.0	0.0	0.0	100.2	*1.00*	*0.00*	*0.00*	*0.80*	*0.17*	*0.04*	*0.00*	*0.00*	*0.00*	*2.00*
21	40 gr24	sk+bn+ch	60.8	0.0	1.2	30.3	4.0	1.8	0.0	1.0	0.0	99.1	*0.98*	*0.00*	*0.01*	*0.82*	*0.12*	*0.05*	*0.00*	*0.01*	*0.00*	*2.00*
22	40 gr25	sk+bn	64.3	0.0	0.0	29.8	4.1	1.4	0.0	0.8	0.0	100.4	*1.03*	*0.00*	*0.00*	*0.80*	*0.13*	*0.04*	*0.00*	*0.01*	*0.00*	*2.00*
23	40 gr26	sk	60.8	0.0	0.0	29.8	5.9	1.5	0.0	0.9	0.0	98.9	*0.97*	*0.00*	*0.00*	*0.80*	*0.18*	*0.04*	*0.00*	*0.01*	*0.00*	*2.00*
24	40 gr27	sk+bn	61.9	0.0	0.0	29.4	2.7	1.9	2.0	0.7	1.2	99.8	*1.01*	*0.00*	*0.00*	*0.80*	*0.08*	*0.05*	*0.03*	*0.01*	*0.01*	*2.00*
25	40 gr28	sk	61.8	0.0	0.0	29.3	3.9	2.6	0.0	0.9	1.0	99.5	*1.00*	*0.00*	*0.00*	*0.79*	*0.12*	*0.07*	*0.00*	*0.01*	*0.01*	*2.00*
26	40 gr29	sk+bn	61.1	0.0	0.0	30.3	3.3	1.2	3.1	0.0	0.0	99.0	*0.99*	*0.00*	*0.00*	*0.82*	*0.10*	*0.03*	*0.05*	*0.00*	*0.00*	*2.00*
27	40 gr30	sk	61.5	1.5	0.0	29.2	5.1	0.9	0.0	1.0	0.0	99.2	*1.00*	*0.01*	*0.00*	*0.79*	*0.16*	*0.02*	*0.00*	*0.01*	*0.00*	*2.00*
28	40 gr31	sk+bn	61.8	0.0	0.0	29.4	5.3	1.4	0.0	0.9	0.0	98.8	*1.00*	*0.00*	*0.00*	*0.79*	*0.16*	*0.04*	*0.00*	*0.01*	*0.00*	*2.00*

24-1053 Table 6 continued…

An	Grain	Association	Pd	Pt	Au	Cu	Fe	Zn	Sn	Te	Pb	Total	*Pd*	*Pt*	*Au*	*Cu*	*Fe*	*Zn*	*Sn*	*Te*	*Pb*	*Total*
29	40 gr32	sk+ch	63.4	0.0	0.0	29.1	5.0	1.7	0.0	0.7	0.0	99.9	*1.01*	*0.00*	*0.00*	*0.78*	*0.15*	*0.05*	*0.00*	*0.01*	*0.00*	*2.00*
30	40 gr33	sk	60.9	0.0	0.0	33.0	4.5	1.0	0.0	0.0	0.0	99.4	*0.96*	*0.00*	*0.00*	*0.87*	*0.14*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
31	40 gr34	sk	64.0	0.0	1.1	28.3	4.9	2.0	0.0	0.0	0.0	100.3	*1.03*	*0.00*	*0.01*	*0.76*	*0.15*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
32	40 gr35	sk	62.8	0.0	0.0	30.1	5.3	1.3	0.0	0.6	0.0	100.1	*1.00*	*0.00*	*0.00*	*0.80*	*0.16*	*0.03*	*0.00*	*0.01*	*0.00*	*2.00*
33	40 gr36	sk+bn	61.8	0.0	1.6	28.1	3.9	1.8	1.1	0.0	0.9	99.2	*1.02*	*0.00*	*0.01*	*0.77*	*0.12*	*0.05*	*0.02*	*0.00*	*0.01*	*2.00*
34	40 gr37	sk	61.6	0.0	0.0	31.2	4.9	2.0	0.0	0.0	0.0	99.7	*0.97*	*0.00*	*0.00*	*0.83*	*0.15*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
35	40 gr38	sk+bn+ch	62.2	0.0	0.0	29.2	5.2	1.3	0.0	0.0	1.2	99.1	*1.01*	*0.00*	*0.00*	*0.79*	*0.16*	*0.03*	*0.00*	*0.00*	*0.01*	*2.00*
36	40 gr39	sk+bn	62.2	0.0	0.0	29.2	4.9	1.3	0.0	1.2	1.0	99.8	*1.00*	*0.00*	*0.00*	*0.79*	*0.15*	*0.03*	*0.00*	*0.02*	*0.01*	*2.00*
37	40 gr40	sk+bn	62.1	0.9	0.0	29.5	5.4	1.1	0.0	0.7	0.0	99.7	*1.00*	*0.01*	*0.00*	*0.79*	*0.16*	*0.03*	*0.00*	*0.01*	*0.00*	*2.00*
38	40 gr41	sk	60.9	0.8	1.1	28.5	4.7	1.9	0.0	0.7	1.1	99.7	*0.99*	*0.01*	*0.01*	*0.78*	*0.15*	*0.05*	*0.00*	*0.01*	*0.01*	*2.00*
39	40 gr42	sk+ch+bn	62.2	0.0	0.0	32.1	1.7	2.3	1.7	0.0	0.0	100.0	*1.00*	*0.00*	*0.00*	*0.86*	*0.05*	*0.06*	*0.02*	*0.00*	*0.00*	*2.00*
40	40 gr43	sk+bn+ch	61.4	0.0	0.0	30.8	4.7	1.5	0.0	0.7	1.3	100.4	*0.98*	*0.00*	*0.00*	*0.82*	*0.14*	*0.04*	*0.00*	*0.01*	*0.01*	*2.00*
41	40 gr44	sk+bn+hb	61.9	0.0	0.0	31.2	5.4	1.2	0.0	0.0	0.0	99.7	*0.99*	*0.00*	*0.00*	*0.82*	*0.16*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
42	40 gr45	sk+kth+bn	52.5	9.2	2.0	27.4	5.2	1.0	1.2	1.0	0.0	99.5	*0.89*	*0.08*	*0.02*	*0.77*	*0.07*	*0.03*	*0.02*	*0.01*	*0.00*	*2.00*
43	40 gr 46	sk	60.0	1.3	1.5	30.3	4.1	1.7	0.0	0.0	0	98.9	*0.98*	*0.01*	*0.01*	*0.82*	*0.13*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
44	40 gr49	sk+$AuPdCu_2$	42.3	4.9	12.4	32.1	1.9	0.0	0.0	1.1	0.0	99.7	*0.75*	*0.05*	*0.17*	*0.95*	*0.07*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
45	40 gr50	sk+bn	55.9	1.8	4.3	29.9	3.6	1.3	2.0	0.8	0.0	99.6	*0.93*	*0.02*	*0.04*	*0.83*	*0.11*	*0.04*	*0.03*	*0.01*	*0.00*	*2.00*
46	40 gr51	sk	60.2	0	0.0	31.2	5.7	1.9	0.0	0.0	0.0	99.0	*0.95*	*0.00*	*0.00*	*0.83*	*0.17*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
47	63 gr1	sk+ch+bn	55.7	1.2	0.0	19.7	1.3	0.4	18.9	0.0	2.1	99.3	*1.01*	*0.01*	*0.00*	*0.60*	*0.04*	*0.01*	*0.31*	*0.00*	*0.02*	*2.00*
48	63 gr2	sk+bn	61.6	0	0.0	30.9	2.3	1.0	3.8	0.0	0.0	99.6	*1.00*	*0.00*	*0.00*	*0.84*	*0.07*	*0.03*	*0.06*	*0.00*	*0.00*	*2.00*
49	63 gr4	sk+bn+ch	60.9	0.0	0.0	33.3	3.7	1.4	0.0	0.0	1.1	100.4	*0.96*	*0.00*	*0.00*	*0.88*	*0.11*	*0.04*	*0.00*	*0.00*	*0.01*	*2.00*
50	63 gr6	sk	63.6	0.9	0.0	29.1	5.7	1.0	0.0	0.0	0.0	100.3	*1.01*	*0.01*	*0.00*	*0.78*	*0.17*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
51	63 gr7	sk	62.6	1.1	0.0	29.2	5.4	1.2	0.0	0.6	0.0	100.2	*1.00*	*0.01*	*0.00*	*0.78*	*0.16*	*0.03*	*0.00*	*0.01*	*0.00*	*2.00*
52	63 gr9	sk+bn+ch	58.0	0.0	4.2	30.1	2.9	2.7	0.0	1.3	0.0	99.2	*0.95*	*0.00*	*0.04*	*0.83*	*0.09*	*0.07*	*0.00*	*0.02*	*0.00*	*2.00*
53	63 gr11	sk	60.9	0.0	1.4	29.5	3.0	1.4	1.3	0.0	2.1	99.6	*1.00*	*0.00*	*0.01*	*0.81*	*0.09*	*0.04*	*0.02*	*0.00*	*0.02*	*2.00*
54	63 gr12	sk	60.4	2.6	0.0	27.8	6.9	1.7	0.0	0.0	0.0	99.4	*0.97*	*0.02*	*0.00*	*0.75*	*0.21*	*0.04*	*0.00*	*0.00*	*0.00*	*2.00*
55	63 gr15	sk+ch+bn	62.7	0.0	0.0	30.1	5.3	1.3	0.0	0.7	0.0	100.1	*1.00*	*0.00*	*0.00*	*0.80*	*0.16*	*0.03*	*0.00*	*0.01*	*0.00*	*2.00*
56	63 gr16	sk+bn+ch	62.7	0.0	0.0	29.0	4.5	1.9	0.0	0.0	1.0	99.1	*1.02*	*0.00*	*0.00*	*0.79*	*0.14*	*0.05*	*0.00*	*0.00*	*0.01*	*2.00*
57	63 gr15-2	sk+bn+ch+chl	63.5	0.0	0.0	30.6	4.6	1.0	0.0	0.0	1.3	101.0	*1.01*	*0.00*	*0.00*	*0.81*	*0.14*	*0.03*	*0.00*	*0.00*	*0.01*	*2.00*
58	63 gr19	sk+bn	57.3	2.9	1.9	30.4	4.5	1.0	0.0	1.3	0.0	99.3	*0.95*	*0.03*	*0.02*	*0.82*	*0.14*	*0.03*	*0.00*	*0.02*	*0.00*	*2.00*
59	125 gr1	sk+bn+ch	62.8	0.0	0.0	30.0	5.4	1.6	0.0	0.0	0.0	99.9	*1.00*	*0.00*	*0.00*	*0.80*	*0.16*	*0.04*	*0.00*	*0.00*	*0.00*	*2.00*
60	125 gr2	sk+bn+ch	59.4	0.0	3.5	28.0	4.1	2.9	0.9	0.0	0.0	98.8	*0.98*	*0.00*	*0.03*	*0.77*	*0.13*	*0.08*	*0.00*	*0.01*	*0.00*	*2.00*
61	125 gr3	sk+bn+ch	60.9	0.0	3.2	29.4	3.8	1.9	0.0	0.8	0.0	100.0	*0.99*	*0.00*	*0.03*	*0.80*	*0.12*	*0.05*	*0.00*	*0.01*	*0.00*	*2.00*
		avr	60.43	0.78	1.07	29.90	4.21	1.36	0.84	0.49	0.40	99.59	*0.98*	*0.01*	*0.01*	*0.80*	*0.13*	*0.04*	*0.01*	*0.01*	*0.00*	

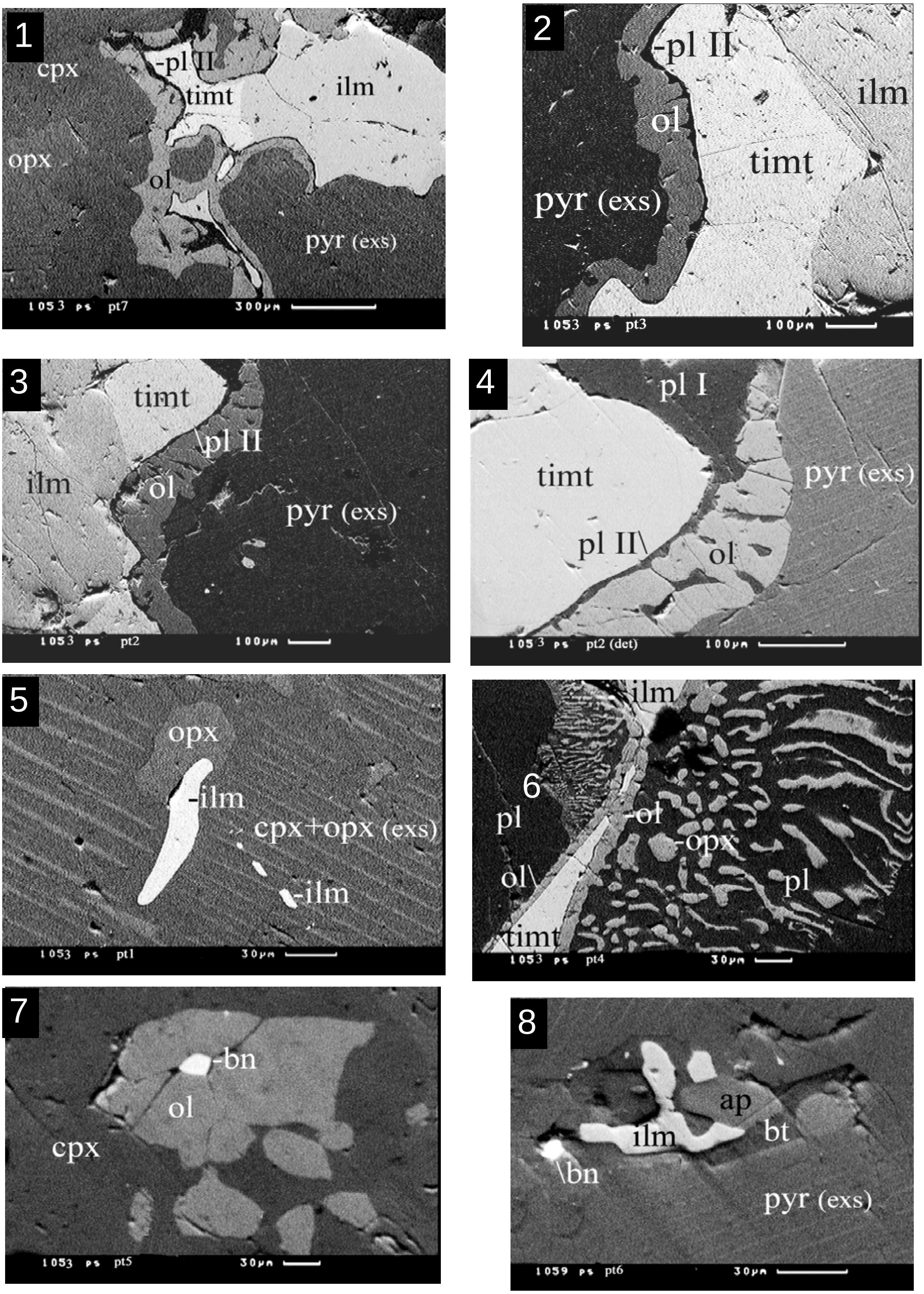
Table 7. Compositions of (Cu,Pd) alloy, nielsenite, unnamed $(Pd,Au)_3Cu$, (Pd,Cu.Sn) alloy; keithconnite, unnamed $AuPdCu_2$ and vasilite in PGM-grains of the heavy mineral concentrates of sample 90-24 1053

Mineral	**(Cu,Pd)**	**Nielsenite**		**Pd_3Cu**	**(Pd,Cu,Sn)**	**keithconnite**		**$AuPdCu_2$**		**vs**
Grain	63 gr14	63 gr14	80 gr4	40 gr10	40 gr11	40 gr2	40 gr45	40 gr49	80 gr3	40 gr48
Association	(Cu,Pd) +nls+ch +bn+copn	(Cu,Pd) +nls+ch +bn+copn	nls+ch +bn	$(Pd,Au)_3Cu$	sk+ (Pd,Cu,Sn)	sk+kth +bn	sk+kth +bn	$AuPdCu_2$ +sk	$AuPdCu_2$ +bn+ch	vs
Analysis #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
wt%										
Pd	46.8	33.6	18.1	32.8	65.6	66.6	69.2	23.1	23.5	74.1
Pt	1.2	1.1	9.5	0.0	0.0	0.0	1.5	6.7	2.1	0.0
Au	1.2	2.5	15.0	54.0	0.0	1.8	0.0	37.1	43.7	0.0
Cu	46.2	61.8	55.5	11.7	13.8	3.3	0.7	29.8	28.8	12.8
Fe	1.9	0.4	1.2	1.3	0.5	0.0	1.0	1.8	0.9	0.0
Zn	1.80	-	-	-	-	-	-	-	-	-
Te	0.0	0.0	0.0	0.0	0.0	24.2	25.7	1.2	0.8	0.0
Sn	0.0	0.0	0.0	0.0	20.2	0.0	0.8	0.0	0.0	0.0
Pb	0.0	0.0	0.0	0.0	0.0	3.4	0.7	0.0	0.0	0.0
S	-	-	-	-	-	-	-	-	-	12.8
sum	99.1	99.4	99.3	99.8	100.1	99.3	99.5	99.7	99.8	99.7
Atomic proportions										
Pd	0.36	0.96	0.57	1.56	0.61	2.81	2.90	0.92	0.95	12.26
Pt	0.01	0.02	0.16	0.00	0.00	0.00	0.03	0.14	0.05	0.00
Au	0.01	0.04	0.26	1.39	0.00	0.04	0.00	0.79	0.95	0.00
Cu	0.59	2.96	2.94	0.94	0.21	0.23	0.05	1.97	1.95	3.59
Fe	0.03	0.02	0.07	0.11	0.01	0.00	0.09	0.14	0.07	0.00
Zn	0.02	-	-	-	-	-	-	-	-	-
Te	0.00	0.00	0.00	0.00	0.00	0.85	0.89	0.04	0.03	0.00
Sn	0.00	0.00	0.00	0.00	0.13	0.00	0.03	0.00	0.00	0.00
Pb	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.00	0.00
S	-	-	-	-	-	-	-	-	-	7.15
sum	1.00	4.00	4.00	4.00	1.00	4.00	4.00	4.00	4.00	23.00

Abbreviatiopns: nls: nielsenite; sk: skaergaardiote; vs: vasilite; kth: keithconnite; $(Pd,Au)_3Cu$: unnamed mineral; (Pd,Cu,Sn): alloy; $AuPdCu_2$: unnamed mineral; (Cu,Pd). alloy; ch: chalcosine; bn: bornite and copn: cobalt pentlandite

PLATES

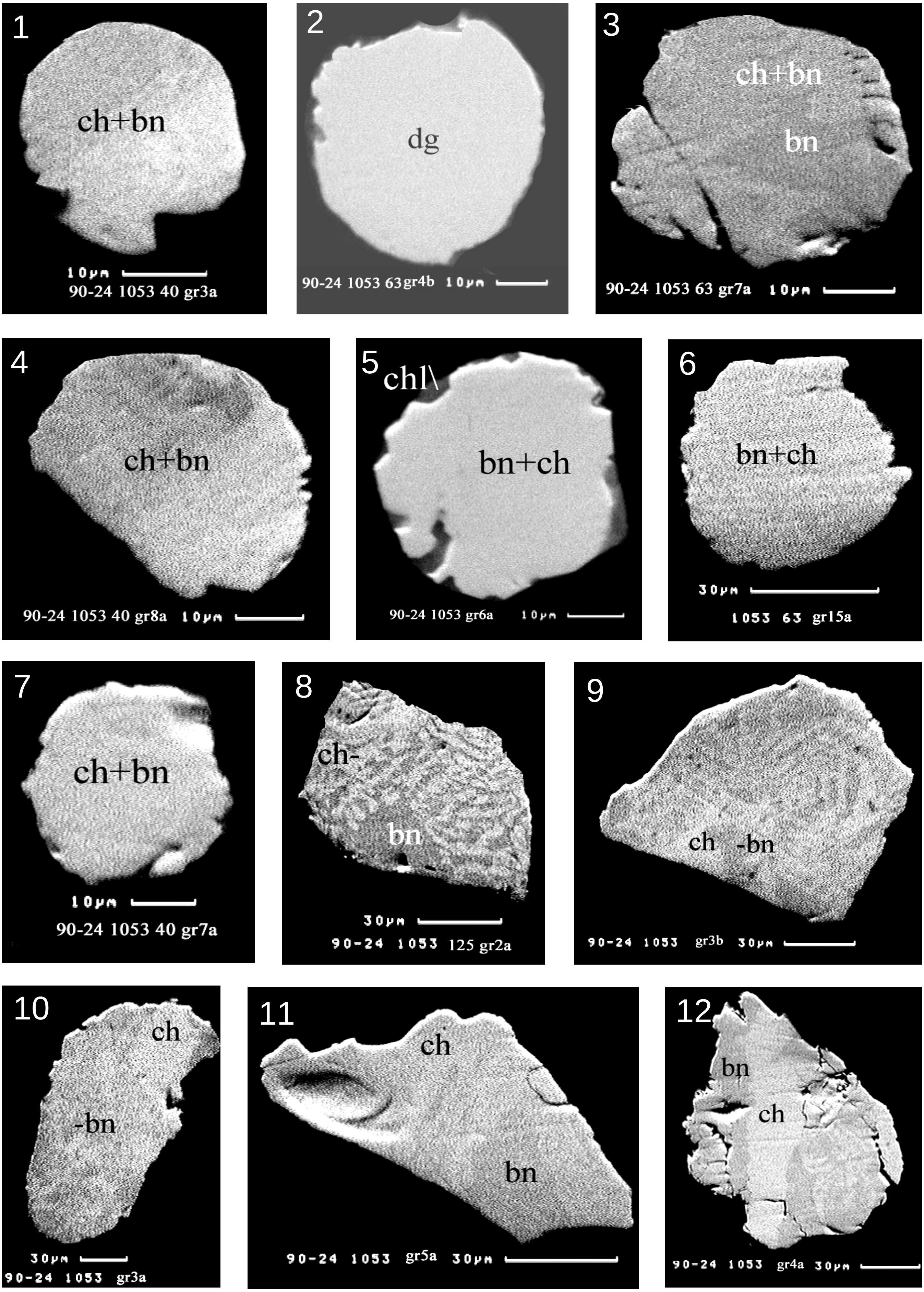
Plate 1



Relationships of rock-forming minerals, Fe-Ti oxides and sulphides in sample 90-24 1053; polished section, SEM-image (BIE).

Plate 2

Sulphide globules of the skaergaard mineralization in sample 90-24 1053; polished section of grains, extracted in the heavy concentrate, SEM-image (BIE). Abbreviations: ch: chalcosine; bn: bornite; gd: digenite; fspn: ferrosaponite; bt: biotite, mt: magnetite; chl: chlorite and ct: calcite.


1
ch+bn
10µm
90-24 1053 40 gr3a
2
dg
90-24 1053 63gr4b 10µm
3
ch+bn
bn
90-24 1053 63 gr7a 10µm
4
ch+bn
90-24 1053 40 gr8a 10µm
5
chl\
bn+ch
90-24 1053 gr6a 10µm
6
bn+ch
30µm
1053 63 gr15a
7
ch+bn
10µm
90-24 1053 40 gr7a
8
ch-
bn
30µm
90-24 1053 125 gr2a
9
ch -bn
90-24 1053 gr3b 30µm
10
ch
-bn
30µm
90-24 1053 gr3a
11
ch
bn
90-24 1053 gr5a 30µm
12
bn
ch
90-24 1053 gr4a 30µm

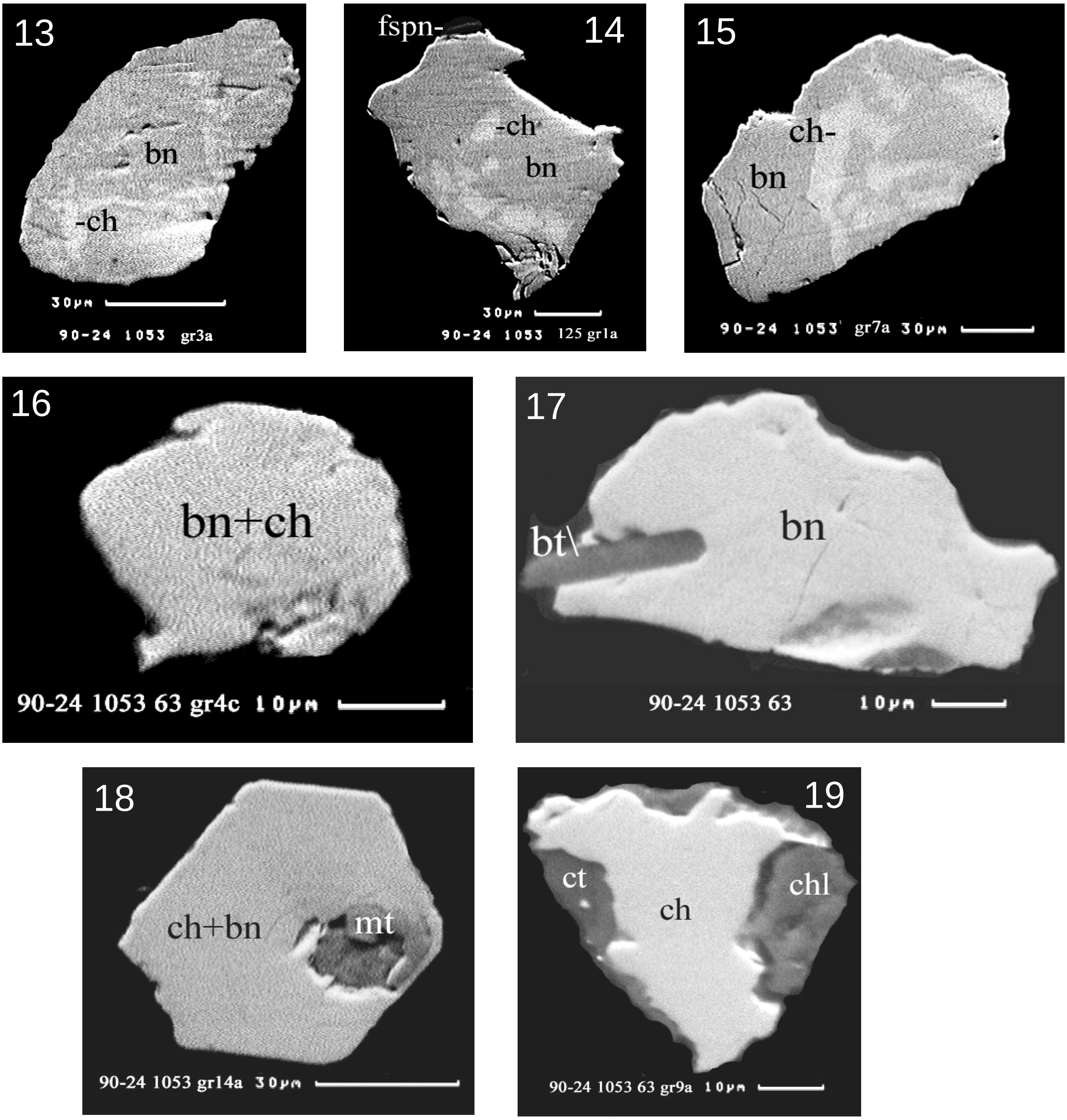
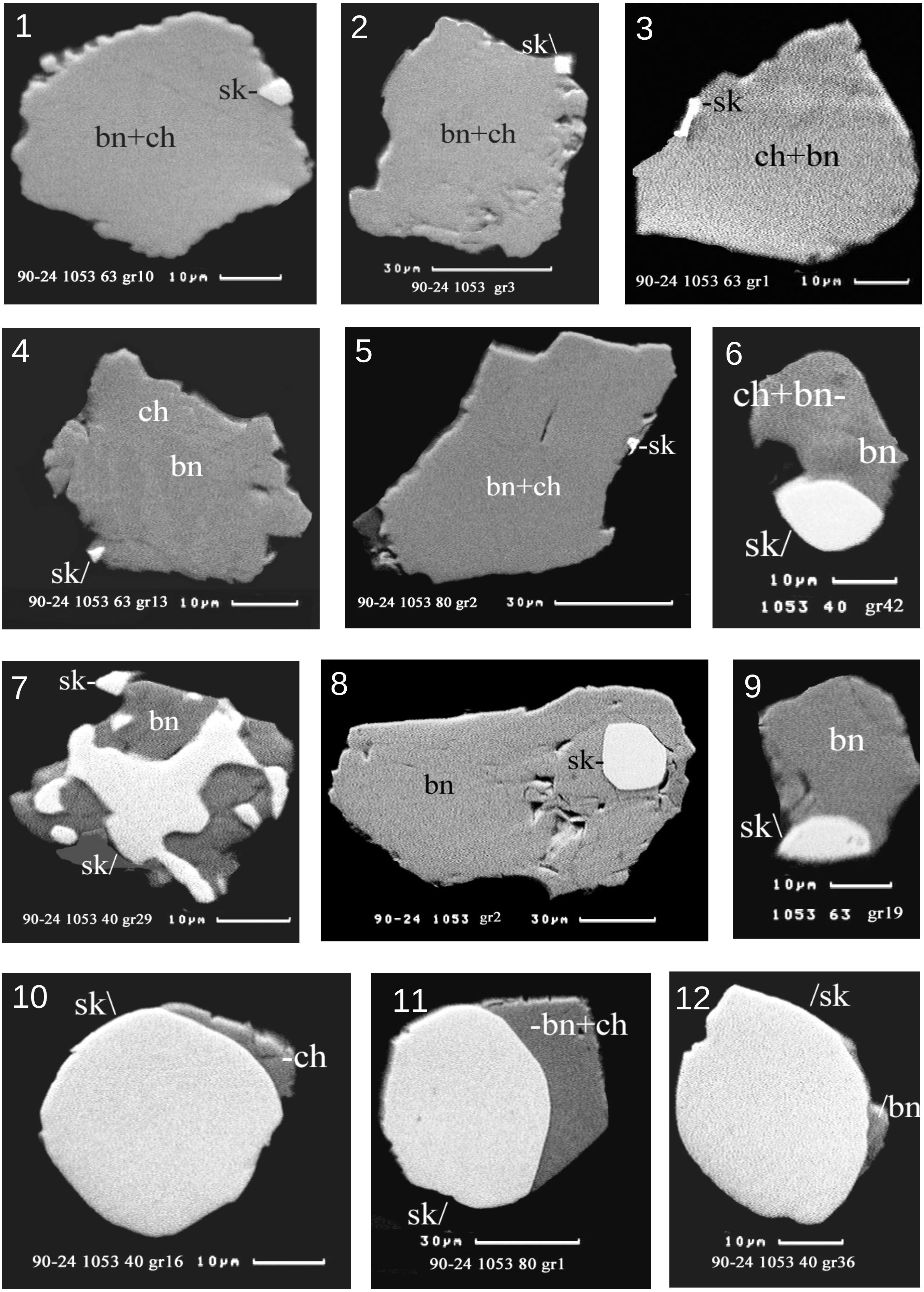
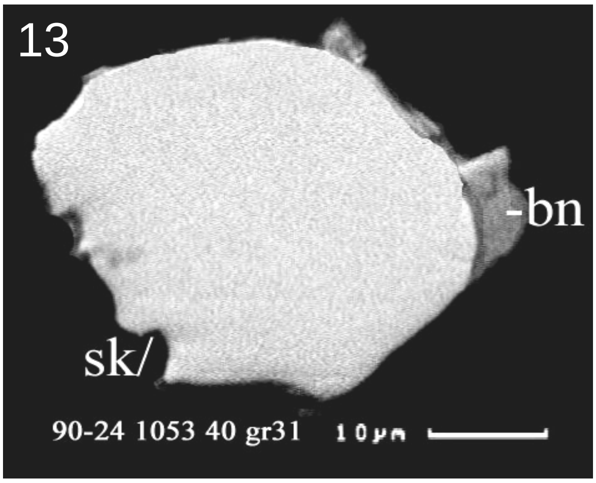

13
bn
-ch
30μm
90-24 1053 gr3a
fspn-
14
-ch
bn
30μm
90-24 1053 125 gr1a
15
ch-
bn
90-24 1053 gr7a 30μm
16
bn+ch
90-24 1053 63 gr4c 10μm
17
bt\
bn
90-24 1053 63 10μm
18
ch+bn
mt
90-24 1053 gr14a 30μm
19
ct
ch
chl
90-24 1053 63 gr9a 10μm

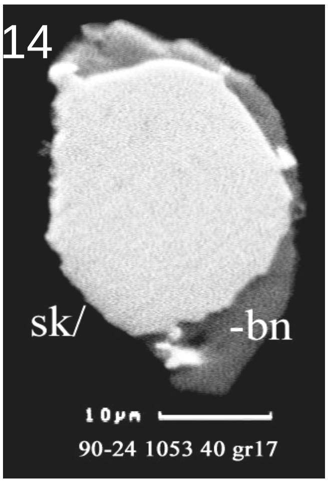
Plate 3

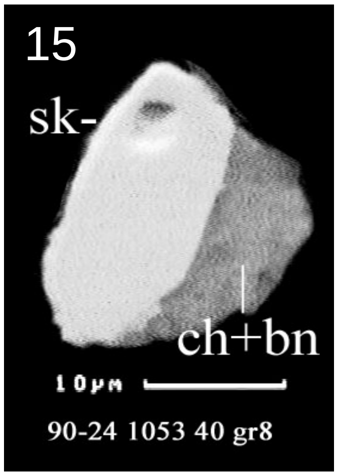
Sulphide globules with inclusions of skaergaardite (**bms**) and skaergaardite particles attached to base metal sulphides (**bms-L**) in the heavy mineral concentrates of sample 90-24 1053; polished section, SEM-image (BIE). Abbreviations: bn: bornite; ch: chalcosine and sk: skaergaardite.

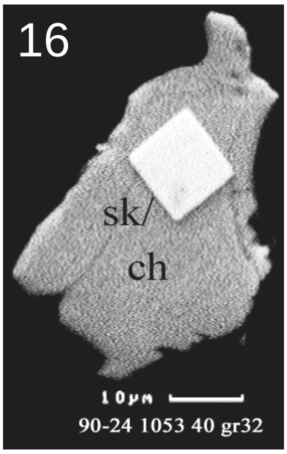


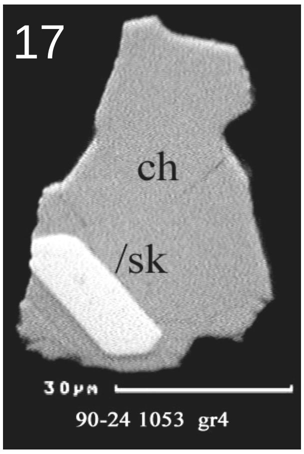
1
sk-
bn+ch
90-24 1053 63 gr10 10μm
2
sk\
bn+ch
30μm
90-24 1053 gr3
3
-sk
ch+bn
90-24 1053 63 gr1 10μm
4
ch
bn
sk/
90-24 1053 63 gr13 10μm
5
-sk
bn+ch
90-24 1053 80 gr2 30μm
6
ch+bn-
bn
sk/
10μm
1053 40 gr42
7
sk-
bn
sk/
90-24 1053 40 gr29 10μm
8
sk-
bn
90-24 1053 gr2 30μm
9
bn
sk\
10μm
1053 63 gr19
10
sk\
-ch
90-24 1053 40 gr16 10μm
11
-bn+ch
sk/
30μm
90-24 1053 80 gr1
12
/sk
/bn
10μm
90-24 1053 40 gr36

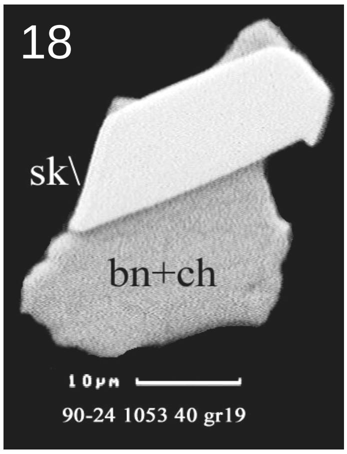

13
-bn
sk/
90-24 1053 40 gr31 10μm

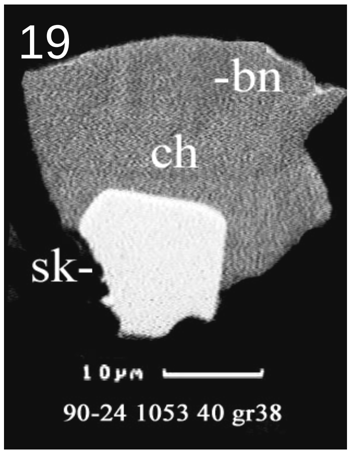

14
sk/
-bn
10μm
90-24 1053 40 gr17

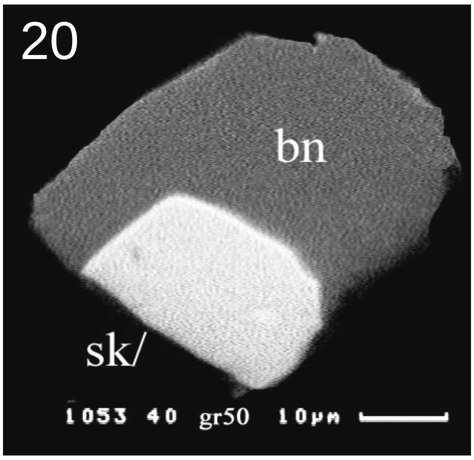

15
sk-
ch+bn
10μm
90-24 1053 40 gr8

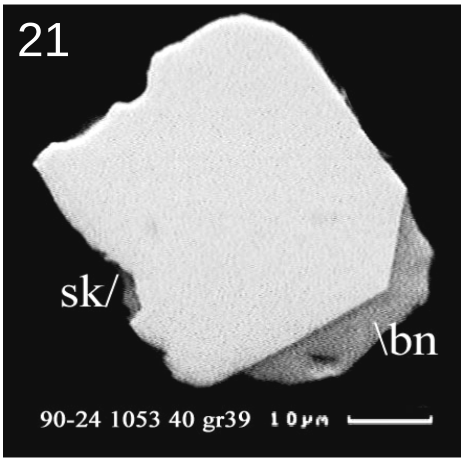

16
sk/
ch
10μm
90-24 1053 40 gr32

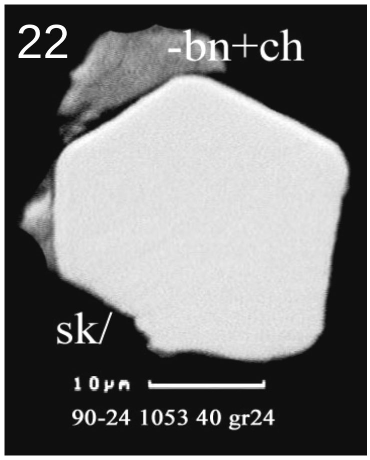

17
ch
/sk
30μm
90-24 1053 gr4

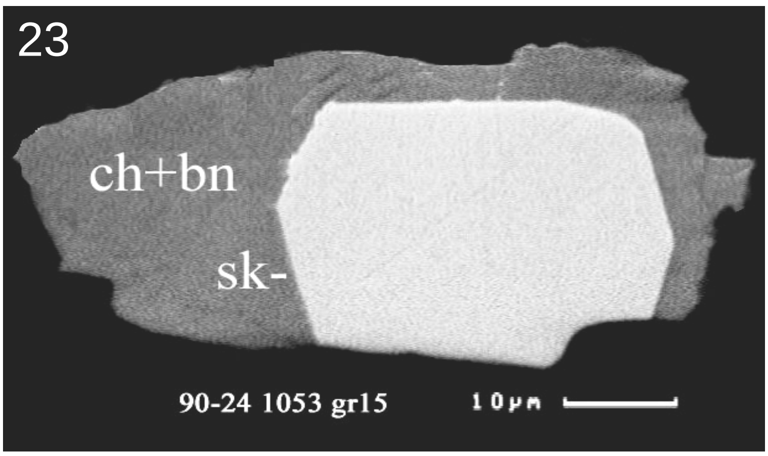

18
sk\
bn+ch
10μm
90-24 1053 40 gr19

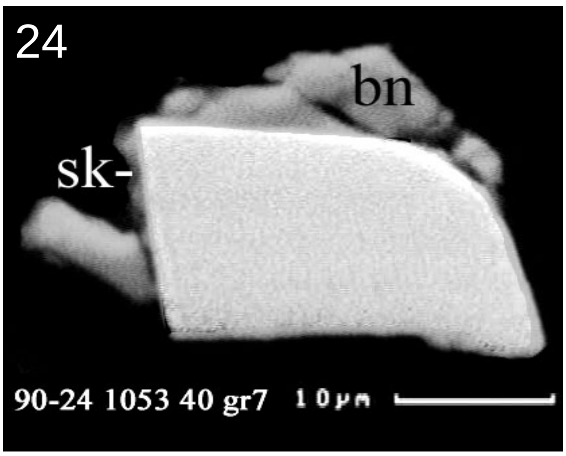

19
-bn
ch
sk-
10μm
90-24 1053 40 gr38

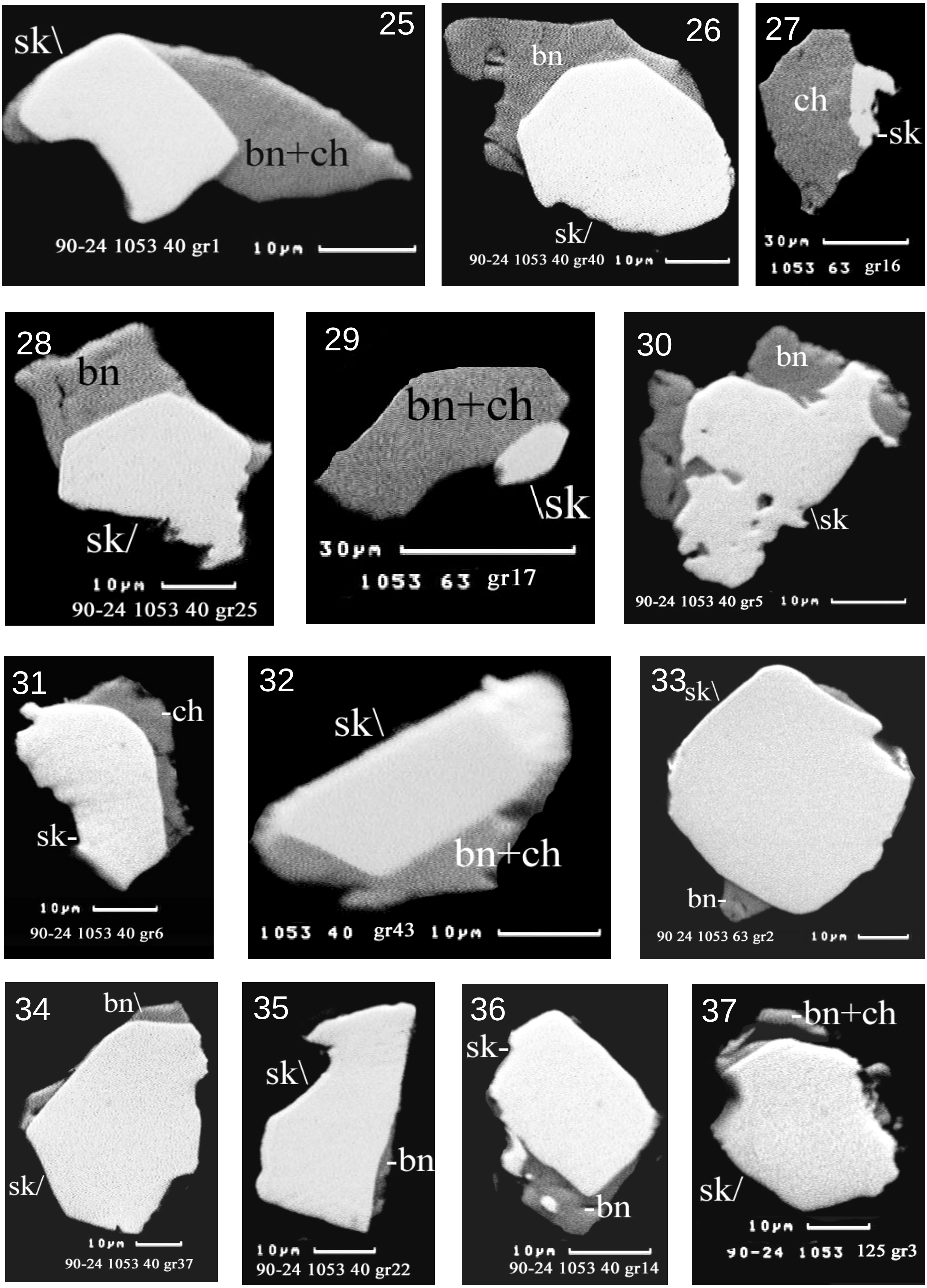

20
bn
sk/
1053 40 gr50 10μm

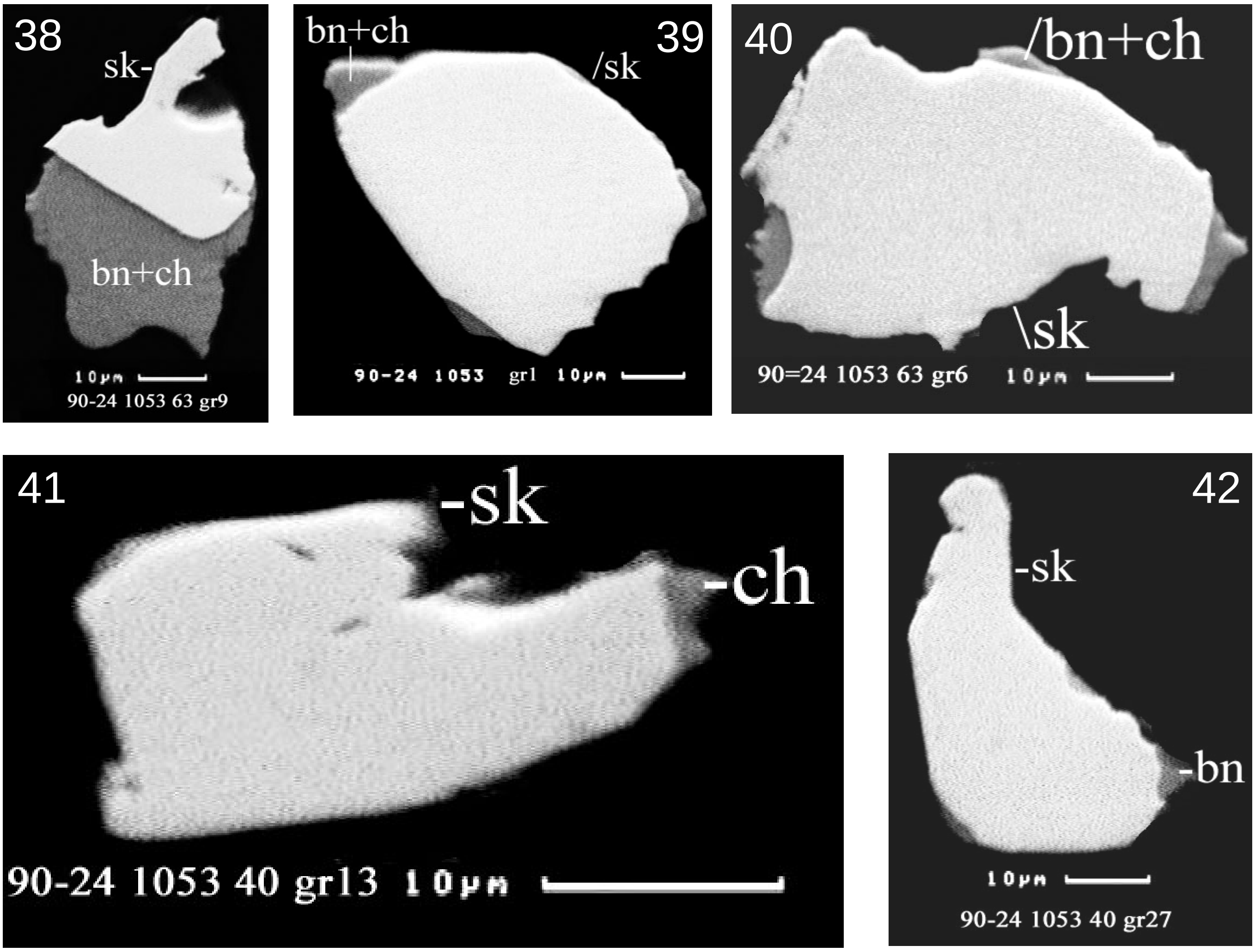

21
sk/
\bn
90-24 1053 40 gr39 10μm


22
-bn+ch
sk/
10μm
90-24 1053 40 gr24


23
ch+bn
sk-
90-24 1053 gr15 10μm

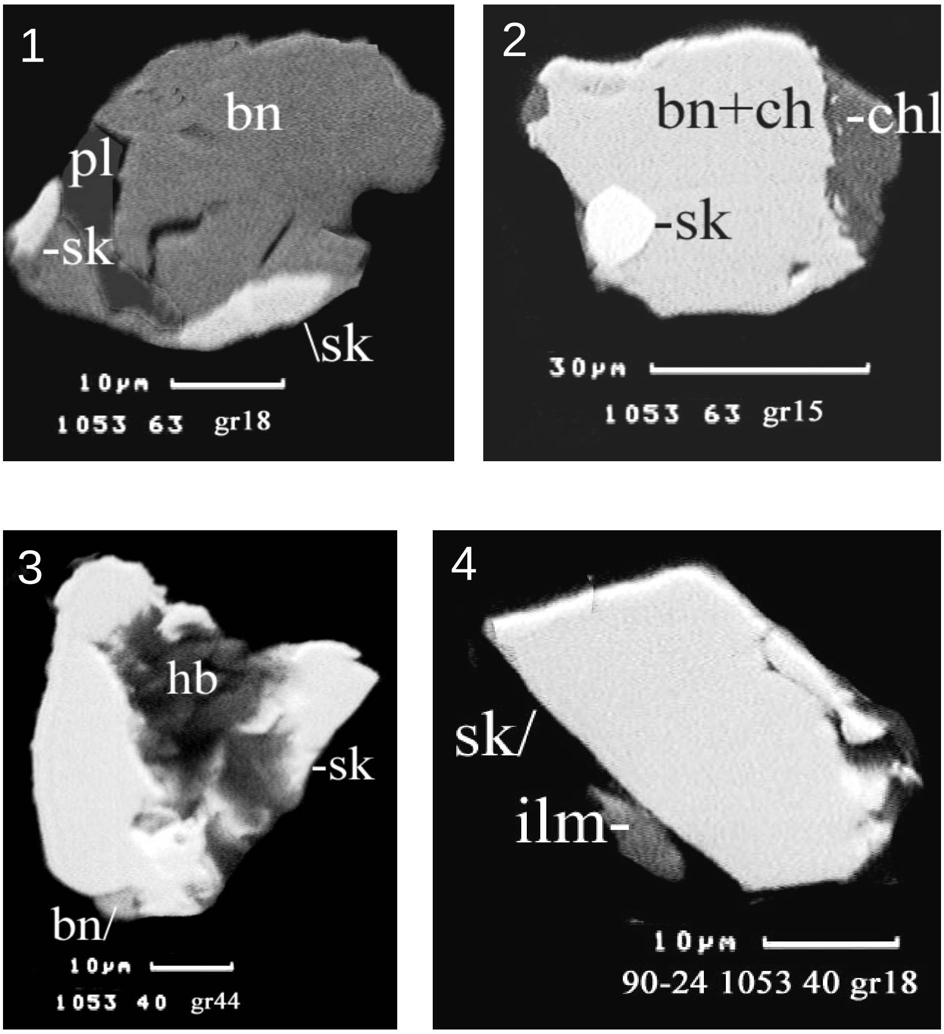

24
bn
sk-
90-24 1053 40 gr7 10μm


25
sk\
bn+ch
90-24 1053 40 gr1
10μm
26
bn
sk/
90-24 1053 40 gr40
10μm
27
ch
-sk
30μm
1053 63 gr16
28
bn
sk/
10μm
90-24 1053 40 gr25
29
bn+ch
\sk
30μm
1053 63 gr17
30
bn
\sk
90-24 1053 40 gr5
10μm
31
-ch
sk-
10μm
90-24 1053 40 gr6
32
sk\
bn+ch
1053 40 gr43
10μm
33
sk\
bn-
90 24 1053 63 gr2
10μm
34
bn\
sk/
10μm
90-24 1053 40 gr37
35
sk\
-bn
10μm
90-24 1053 40 gr22
36
sk-
-bn
10μm
90-24 1053 40 gr14
37
-bn+ch
sk/
10μm
90-24 1053 125 gr3



38
sk-
bn+ch
10μm
90-24 1053 63 gr9
39
bn+ch
/sk
90-24 1053 gr1 10μm
40
/bn+ch
\sk
90=24 1053 63 gr6 10μm
41
-sk
-ch
90-24 1053 40 gr13 10μm
42
-sk
-bn
10μm
90-24 1053 40 gr27

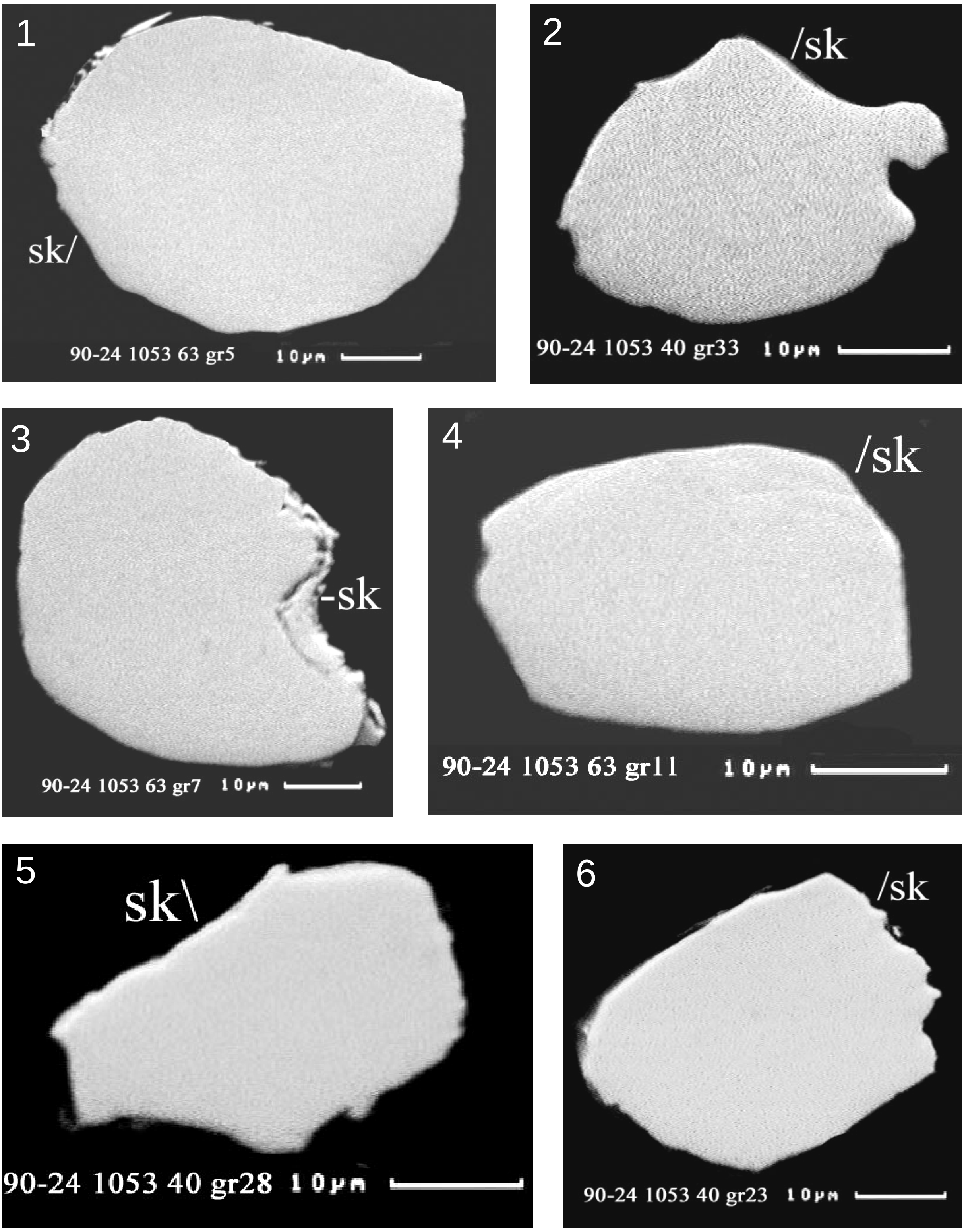
Plate 4



PGM grains attached to gangue or to gangue and sulphides
in the heavy mineral concentrates of sample 90-24 1053; polished section,
SEM-image (BIE). Abbreviations: sk: skaergaardite; bn: bornite; ch: chalcosine;
pl: plagioclase; hb: hornblende; chl: chlorite and ilm: ilmenite.

Plate 5

Completely liberated grains of skaergaardite (**L**) in the heavy concentrates of sample 90-24 1053; polished section, SEM-images (BIE). Abbreviations: sk: skaergaardite.


1
sk/
90-24 1053 63 gr5
10μm
2
/sk
90-24 1053 40 gr33
10μm
3
-sk
90-24 1053 63 gr7
10μm
4
/sk
90-24 1053 63 gr11
10μm
5
sk\
90-24 1053 40 gr28
10μm
6
/sk
90-24 1053 40 gr23
10μm

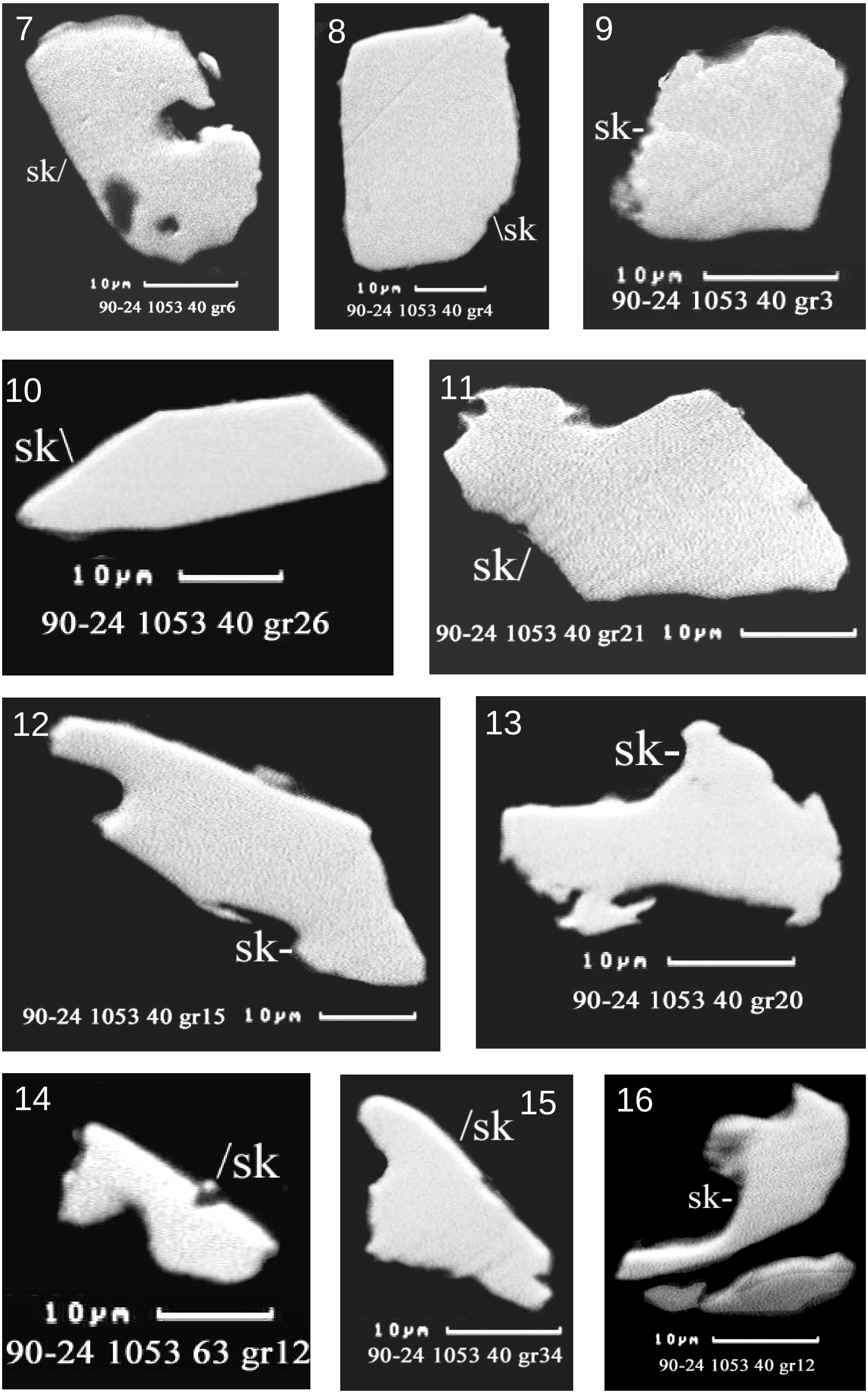
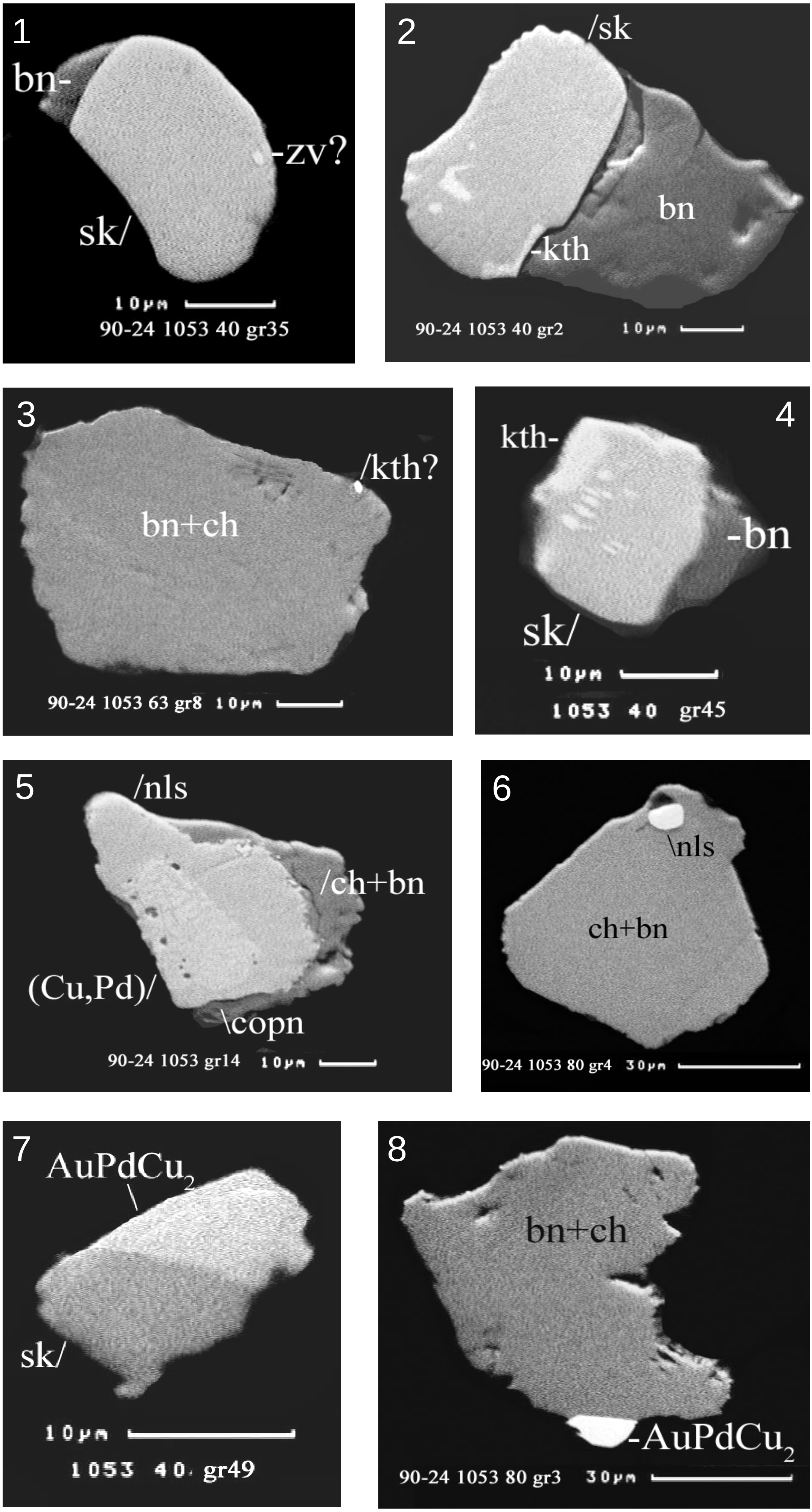
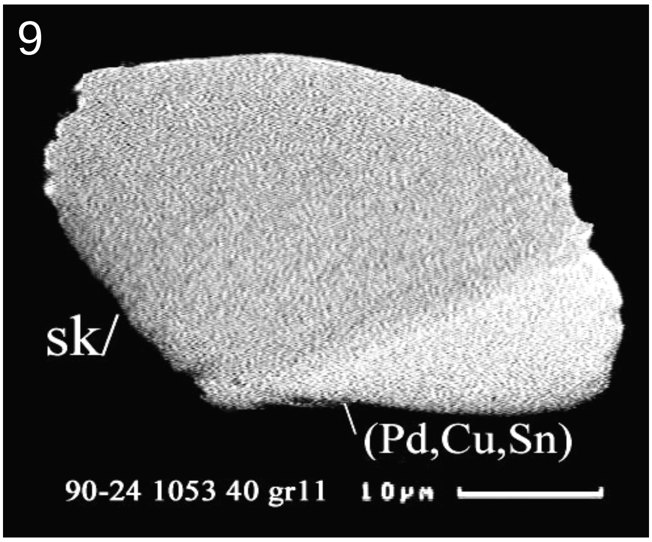
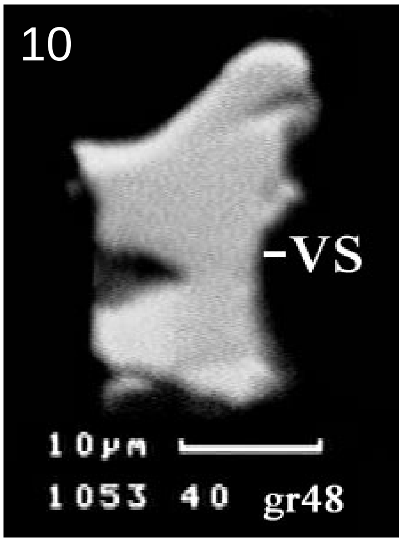

7
sk/
10µm
90-24 1053 40 gr6
8
\sk
10µm
90-24 1053 40 gr4
9
sk-
10µm
90-24 1053 40 gr3
10
sk\
10µm
90-24 1053 40 gr26
11
sk/
90-24 1053 40 gr21 10µm
12
sk-
90-24 1053 40 gr15 10µm
13
sk-
10µm
90-24 1053 40 gr20
14
/sk
10µm
90-24 1053 63 gr12
15
/sk
10µm
90-24 1053 40 gr34
16
sk-
10µm
90-24 1053 40 gr12

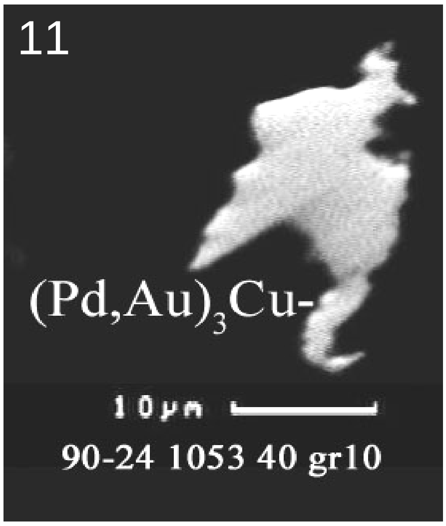
Plate 6

PGM grains containing zvyagintsevite (1), keithconnite (2-4), nielsenite and (Cu,Pd) alloy (5, 6), unnamed $AuPdCu_2$ (7, 8), (Cu,Pd,Sn) alloy (9), vasilite (10) and unnamed $(Pd,Au)_3Cu$ (11) in the heavy mineral concentrates of sample 90-24 1053; polished section, SEM-image (BIE). Abbreviations: Sk: skaergaardite; zv: zvyagintsevite; kth: keithconnite; ch: chalcosine; nls: nielsenite; vs: vasilite; (Cu,Pd): alloy; $AuPdCu_2$: unnamed mineral; (Pd,Cu,Sn): alloy; $(Pd,Cu)_3Cu$: unnamed mineral; bn: bornite and copn: cobalt pentlandite.


1
bn-
-zv?
sk/
10μm
90-24 1053 40 gr35
2
/sk
bn
-kth
90-24 1053 40 gr2
10μm
3
/kth?
bn+ch
90-24 1053 63 gr8 10μm
4
kth-
-bn
sk/
10μm
1053 40 gr45
5
/nls
/ch+bn
(Cu,Pd)/
\copn
90-24 1053 gr14 10μm
6
\nls
ch+bn
90-24 1053 80 gr4 30μm
7
AuPdCu2
\
sk/
10μm
1053 40. gr49
8
bn+ch
-AuPdCu2
90-24 1053 80 gr3 30μm


9
sk/
(Pd,Cu,Sn)
90-24 1053 40 gr11
10μm


10
-VS
10μm
1053 40 gr48


11
(Pd,Au)3Cu-
10μm
90-24 1053 40 gr10