DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/104

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Part 20: Sample 90-24 1048

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G E U S

Abstract

The report presents the results of mineralogical investigations of sample 90-24 1048 from the PGE-Au mineralisation of the Platinova Reef in the Skaergaard intrusion. The sample represents the peak of the Pd4a level in the core 90-24. Assays show 630 ppb Pd, 52 ppb Au, and 50 ppb Pt for the 1m sampling interval.

The sample (1140 g) was crushed for short periods (0.3-0.5 min) in small portions using a shatter box with small cavities (200 ml) and sieved after each crushing session to remove the fine fraction (sieve -125 µm). The residual coarse fraction >125 µm was re-crushed until the entire sample had attained the desired maximum grain size.

After complete crushing the material was passed through the following sieves: 1) <40, 2) 40-63, 3) 63-80, 4) 80-125 µm. All fractions were subsequently subjected to wet magnetic separation.

The non-magnetic parts of every fraction from the sample 90-24 1048 were hydroseparated using the computer controlled hydroseparator CNT HS-11. Monolayer polished sections were produced from the obtained heavy concentrates of each grain size fraction. The polished sections and one of the core rock were investigated under the scanning electron microprobe. No precious metal grains were observed in the magnetic grain size fractions.

The gabbroic bulk rock of the sample 90-24 1048 shows the characteristic reaction relationships between cumulus and inter-cumulus phases, such as rims of olivine and anorthite rich plagioclase at the boundaries between Fe-Ti-oxides and pyroxenes. In general, the sample is “dry” with H_2O-bearing minerals occurring only locally 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 Cu-sulphides – bornite and chalcosine, rare chalcopyrite, pentlandite-(Co) and unnamed Cu_2FeS_3(?). Several of these droplets and sulphide grains contain inclusions of PGMs.

As the result of microprobe investigations of the un-magnetic heavy mineral concentrates we selected a representative suite of 122 precious metal grains for more detailed studies. The dominating precious metal mineral is skaergaardite (Pd,Au,Pt)(Cu,Fe,Zn) with 95.3 vol. %, followed by several minor minerals (~5 % of all precious metal minerals of the sample) including: (1) tetra-auricupride (Au,Pd,Pt)Cu (1.2 %), (2) unnamed $(Au,Pd,Pt)_3Cu$ (1.6 %), (3) vasilite $(Pd,Cu)_{16}S_7$ (1.0 vol. %), (4) (Pd,Pb,Sn,Te,Cu) alloys (incl. zvyagintsevite, atokite, keithconite – together 0.5 %), and (5) unnamed Pd_2Te (0.3 %). The grain size of precious metal minerals (ECD) varies from 1 to 93 µm with an average of 30 µm.

The average composition of skaergaardite (analyses from 98 grains) is (wt. %):

Pd: 60.8, Pt: 0.8, Au: 1.2, Cu: 29.2, Fe: 4.5, Zn: 2.0, Sn: 0.3, Te: 0.3, Pb: 0.6, with a total of 99.7. The composition corresponds to the formula:

$$(Pd_{0.98}Pt_{0.01}Au_{0.01})_{1.00}(Cu_{0.79}Fe_{0.14}Zn_{0.05}Te_{0.01}Pb_{0.01})_{0.99}.$$

The estimated bulk composition of the sample (assays of whole rock in brackets) is (ppb): Pd 688 (630), Au 34 (52), Pt 10 (50). Pd is hosted in skaergaardite (669 ppb) and in other precious metal minerals (totalling 19 ppb). Pt is hosted in skaergaardite (and in some Au alloys), Au is distributed between its own minerals (tetra-auricupride + Au_3Cu – 21 ppb) and skaergaardite (13 ppb).

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

Introduction

The report describes the mineralogy of sample 90-24-1048 from Pd4a level some 10m above the main peak of palladium in the Pd5 level of the "Platinova Reef" of the Skaergaard intrusion (Andersen et al., 1998; Nielsen et al, 2005). The report is based on the data recovered from HS concentrates produced using the Hydroseparator CNT HS-11 and one polished section of the core rock. Monolayer polished sections of the HS concentrates and one polished section of the core rock have been studied using electron microscopy and electron microprobe analysis (Camscan-4DV, Link AN-10 000). The report gives descriptions of the grain characteristics, the parageneses, and the compositional variations within the identified groups of minerals, alloys, sulphide droplets and host gabbro.

Sample 90-24, 1048

Drill core sample 90-24 1048 (1140 g) consists of gabbro rich in FeTi-oxides and was collected from 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 slopes of Basistoppen. The core has previously been sampled for other purposes. The sample collects 1/3 of the diameter of the preserved core between 1048 and 1049 m in the Pd4a level (Nielsen et al., 2005). Assays show 630 ppb Pd, 52 ppb Au, and 50 ppb Pt for this interval.

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003).The heavy mineral concentrates, enriched in precious metal minerals were obtained using the computer controlled Hydroseparator CNT HS-11 and patented glass separation tube (GST, see website of Center for New Technologies, www.cnt-mc.com.). Final HS concentrates were obtained using saturated NaCl solution to provide a better recovery of the heavy media.

One chip of the core was used for a polished section. The remaining core material was crushed to –125 µm. After complete grinding, the sample was passed through standard sieves with water (wet sieving): <40 µm (428.6 g)[*], 40-63 µm (134.6 g), 63-80 µm (93.2 g), 80-125 µm (363.6).

After wet magnetic separation fractions <40 µm, 40-63 µm, 63-80 µm, 80-125 µm were processed in hydroseparator CNT HS-11. Monolayered polished sections were produced from all grain size fractions of heavy HS-concentrates.

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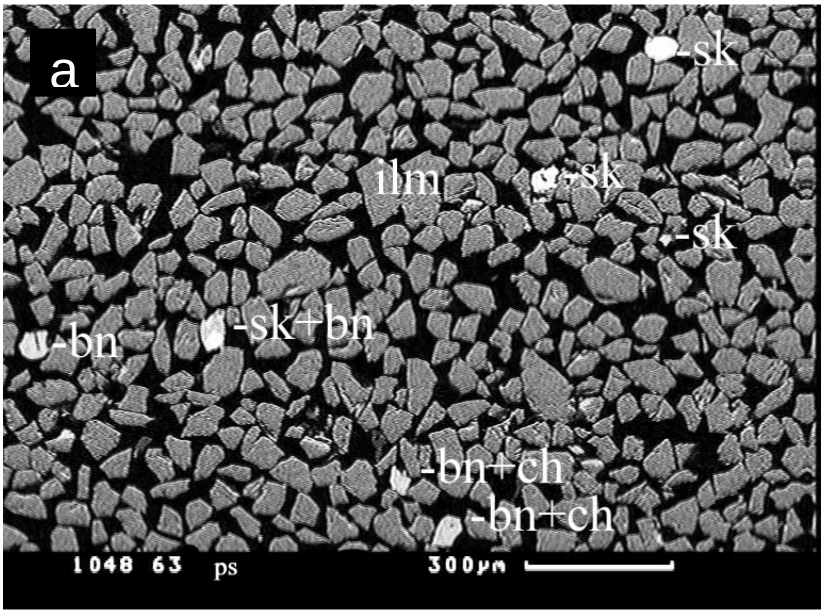
[*] Weigh of HS-tailings



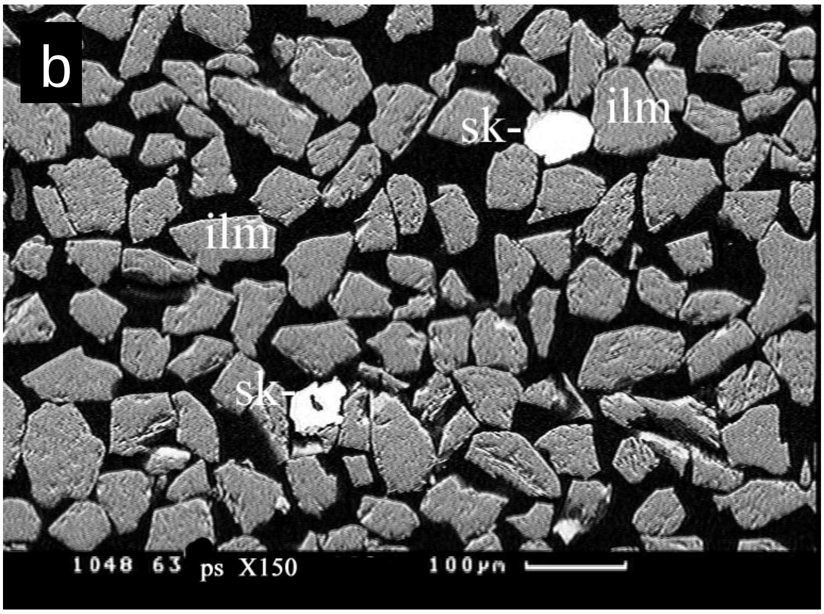


Fig 1. Polished sections of heavy mineral concentrate, fraction 40 63 µm (a – X70; b – X150), sample 90-24 1048, SEM-images (BIE).

Abbreviations: ilm: ilmenite; sk: skaergaardite: bn: bornite; ch: chalcosine.

Results

Rock forming minerals and sulphide mineralogy

Silicates and FeTi-oxides

The silicates and oxides related to sulphides are: 1) *plagioclase*, An_{42-47} (Table 1, analyses 1-3); 2) *monoclinic ferrous pyroxene*, Mg# = 0.61-0.65 (Table 1, analyses 4-6); 3) *orthorhombic ferrous pyroxene*, Mg# = 0.50-0.55 (Table 1, analyses 7-8); 4) Fe-rich *olivine,* Mg# = 0.43-0.45 (Table 1, analyses 9-11); Fe-Ti oxides including 5) *ilmenite* (Table 1, analyses 12-14) and 6) *titanomagnetite* (Table 1, analyses 15-17). Monoclinic and orthorhombic pyroxenes form characteristic exsolution textures (see Plate 1).

The Fe-Ti-oxides occur as aggregates of anhedral grains, 1-3 mm in size. They fill space between grains of plagioclase and pyroxenes (see Plate 1). At the contact between pyroxenes and Fe-Ti-oxides these aggregates often are rimmed by fayalite and anorthite (Plate 1, images *1-3*) as described in Holness et al., 2011. There are also areas in the section were the rock does not show these reaction rims. (Plate 1, images *4-6, 8*).

The gabbro of the sample 90-24 1048 is a “dry” rock. In the polished section no minerals containing volatile elements found (Plate 1). However, chlorite and calcite were identified in the heavy mineral concentrate as grains related to sulphide globules (Plate 2, #*24-26*; Plate 3, #*3*; Plate 4, #*8, 9*).

Sulphides

The gabbro is relatively poor in sulphide. In the investigated polished section just one bornite grain was found as a fine inclusion (~10 μm) in an intergrowth with titanomagnetite and apatite in a pyroxene-rich aggregate (Plate 1, image *7*).

However, the nonmagnetic heavy mineral concentrates are ilmenite-rich products (> 95 %) enriched in grains of sulphide and PGMs (Fig.1). The sulphide grains are represented by droplet-like microglobules (Plate 2, #*1-14*; Plate 3, #*1, 5-7* etc) of up to 0.1 mm in size and irregular aggregates (Plate 2, #*15-39* etc). Inclusions of rock-forming minerals - plagioclase (Plate 2, #*22*; Plate 4, #*3*), pyroxenes (Plate 4<#*1*), olivine (Plate 4, #*2*) ilmenite (Plate 2, #*23*; Plate 4, #*4-6*), chlorite (Plate 2, #*24-26*; Plate 4, #*8, 9*), calcite (Plate 4, #*10*) and even ThO_2 (Plate 4, #*7*) often occur in the marginal parts of sulphide grains.

The sulphide grains and aggregates are dominantly composed of bornite and chalcosine (see Plates 2 and Plate 3) and sometimes chalcosine, only (Plate 2, #*14*: Plate 3, #*47*). The volume ratio of the Cu-sulphides varies significantly from grain to grain (see Plate 2). In the microglobules bornite and chalcosine form classic exsolution textures (see Plates 2-4).

Bornite and chalcosine are are the dominating sulphides. In several sulphide globules was also found chalcopyrite (Plate 3,#*25*), pentlandite-(Co) (Plate 3, #*20, 22, 37*) and the unnamed Cu-Fe sulphide Cu_2FeS_3(?) (Plate 3, #*13*; Plate 4, #*7*). The composition of bornite (Table 2, analyses 1, 4, 7. 9. 11, 12, 14-17, 28) and chalcosine (Table 2, analyses 2, 3, 5, 6, 8, 12, 13, 18) are near-stoikiometric. Pentlandite contains 11.3-23.3 % Co (Table 2, analyses 19, 20). The unnamed sulphide with a composition close to Cu_2FeS_3 (Table 2, analyses 22, 23) is repeatedly found and represents a hitherto not named or described phase occurring in nature.

Precious metal minerals: recovery, grain size and relations to host rock

Recovery

During the SEM studies of the polished section of sample 90-24 1048 (Plate 1, #*3, 8*) only one grain of skaergaardite was found. It occurs as an inclusion in ilmenite

However, the heavy mineral concentrates have yielded many precious metal mineral grains. A representative selection of 122 grains with a wide size range (from <40 µm up to 80-125 µm) was studied in detail. Eight different precious metal minerals and phases are documented and include (see also Table 3):

1. *Skaergaardite* (Pd,Au,Pt)(Cu,Fe,Zn,Te,Pb) – 110 grains,
2. *Unnamed* $(Au,Pd,Pt)_3(Cu,Fe)$ –3 grains
3. *Tetra-auricupride* (Au,Pd,Pt)(Cu,Fe) – 4 grains;
4. *Vasilite* $(Pd,Cu)_{16}S_7$ – 5 grains;
5. *Unnamed* Pd_2Te – 2grains.
6. *Zvyagintsevite* $Pd_3(Pb,Cu,Sn)$ – 9 grains,
7. *Atokite* $Pd_3(Sn,Cu,Pb,Te)$ – 6 grains,
8. *Keithconite* $Pd_3(Te,Cu,Pb,Sn)$ – 3 grains.

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

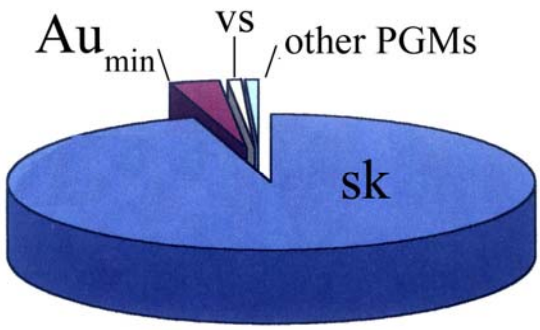


Fig. 2. Relative content of precious metal minerals, sample 90-24 1048 (see Table 3). Skaergaardite: 95.3 vol.%; tetra-auricupride and unnamed $(Au,Pd)_3Cu$: 2.8 vol.%; vasilite: 1 vol.%; and other PGM (zvyagintsevite, atokite, keithconnite, unnamed Pd_2Te) 0.8 vol.%.

Grain size

Grain sizes are measured as the effective diameter of the grains (ECD) by using the “imageJ” software. The grain size varies from 1 to 93 µm with an average of 30 µm (Table 4; Fig. 3).

The histogram (Fig. 3) shows the normal distribution of grain sizes for the statistical selection (n=122). By size of the precious metal mineral grains are distributed as follows:

Grain size, µm	Number of grains
0-10	13
10-20	23
20-30	30
30-40	28
40-50	15
50-60	8
60-70	1
70-80	2
80-90	1
90-100	1

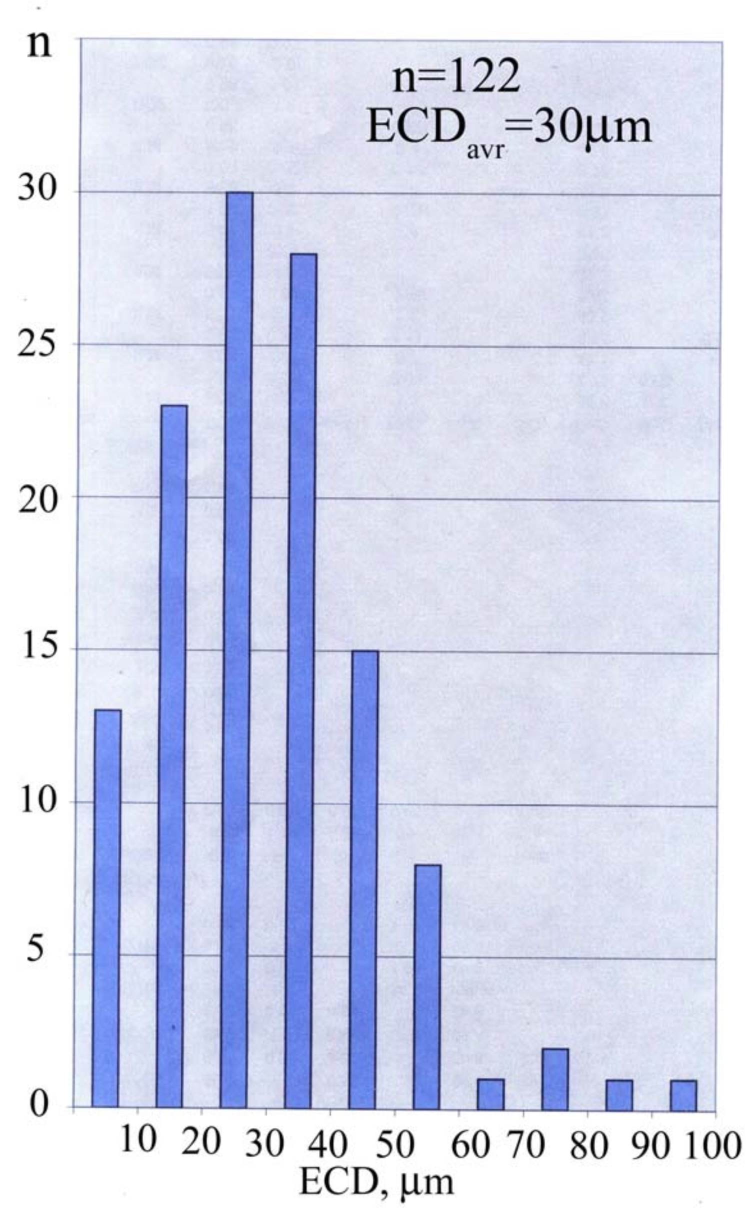


Fig 3. Histogram of the size distribution of precious metal mineral grains (n=122) in the heavy mineral concentrates of sample 90-24 1048. [Skriv et citat fra dokumentet, eller gengiv en interessant pointe. Du kan placere tekstfeltet et hvilket som helst sted i dokumentet. Brug fanen Tegnefunktioner til at redigere formateringen i tekstfeltet med uddraget.]

The SEIs (scanning electron images) show that the majority of the grains of precious metals are well preserved and have retained their primary shape and size (Plates 3-7). The grains were not been broken during the production of the concentrates. The largest proportion of PGM grains is in the <40 µm fraction.

Petrographic observations

The perfect separation of accessory minerals was achieved by gentle crushing/disintegration of the sample and preserved primary grain size, and ensured recovery of most of the information for the evaluation of the mineral geneses. The concentrates provide significant information for the reconstruction of the primary shape and size of accessory minerals and phases, together with the parageneses and the paragenetic relationship to the host rock mineralogy.

In the heavy mineral concentrates of sample 90-24 1048 (n=122) the precious metal mineral grains occur in the following mineral associations (Fig. 4; Table 5):

Association	PGM grains, number	PGM-grains, vol. %
L	33	29
L^+	11	7.2
bms-L	18	31.4
bms	47	26.3
sag	6	3.3
ag	3	2.8

Table 5. Different associations of precious metal mineral grains in heavy mineral concentrates of the sample 90-24 1048.

L - completely liberated (free) particles; **L^+**- more than one precious metal minerals completely liberated (free) particles, **bms-L** - liberated particles with <10 % attached base metal sulphides; **bms** - intergrowths with base metal sulphides (bornite, chalcosine, pentlandite, unnamed Cu_2FeS_3?); **sag** - sulphide and gangue (pyroxenes, plagioclase, ilmenie, olivine, chlorite, calcite, thorianite) attached to PGMs; **ag** - precious metal minerals attached to gangue.

The proportion of completely liberated PGM grains (**$L+L^+$**) in the heavy mineral concentrate is 36.2 %. Grains attached to bms (**bms**+**bms-L**+**sag** associations) however dominate (61 %, see Fig 4). Only 2.8 % of the PGM grains are attached to gangue (**ag** association).

Based on SEIs, precious metal minerals in the heavy concentrates can be divided into different groups:

1. skaergaardite grains-intergrowths with base metal sulphides (**bms, bms-L**), - (Plate 3);
2. skaergaardite grain intergrowths with gangue or with gangue and base metal sulphides (**sag** and **ag**) – (Plate 4);
3. completely liberated skaergaardite grains (**L**) – (Plate 5);
4. grains containing PGMs other than skaergaardite (Plate 6);
5. grains of gold mineral (Plate 7).

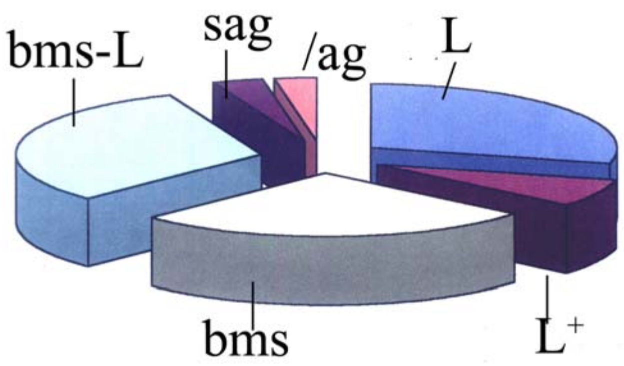


Fig. 4. Precious metal minerals grouped by association, sample 90-24 1048; see Table 5.

L: completely liberated (free) particle, 29%; **L**$^{+}$: more than one precious metal mineral, completely liberated (free) particles, 7.2%; **bms**: PGMs attached to base metal sulphides, 26.3%; **bms-L**: base metal sulphides attached to PGMs, 31.4%; **sag**: PGMs attached to sulphides and gangue, 3.3%; **ag**: precious metal minerals attached to gangue, 2.8%.

Description and composition of precious metal minerals

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

The Skaergaard intrusion is the type locality of skaergaardite (PdCu) and first described by Rudashevsky et al. (2004).

Description

Skaergaardite is the dominant Pd mineral in heavy mineral concentrates of sample 90-24 1048 (95.3 vol.%). It is found in the concentrates as:

1. liberated (free) grains: **L** (Plate 5);
2. grains in intergrowths with base metal sulphides (bornite, chalcosine, pentlandite and unnamed Cu_2FeS_3?) - **bms** (Plate 3, #*1-25, 31, 32, 37, 48*; Plate 6, #*3, 8,15, 16*), **bms-L** (Plate 3, #*26-30, 33-35, 38-47, 49*; Plate 6, # *1, 2, 4, 5, 10, 12*);
3. grains in intergrowths with sulphide and gangue (plagioclase, pyroxenes, ilmenite, olivine, chlorite, calcite and thorianite) – **sag** (Plate 4, #*2, 3, 6-10*) or with gangue only -: **ag** (Plate 4, #*1, 4, 5*: Plate 6, #*11*);
4. grains in intergrowths with other PGMs – zvyagintsevite (Plate 6, #*1-9*), atokite (Plate 6, #*10-13*), vasilite (Plate 6, #*19*) and (Pd,Cu,Sn) (Plate 6, #*16*).

Beside liberated grains of skaergaardite (Plate 5) also occur in association with base metal sulphides (see Plate 3; Plate 4, #*3, 6-10*; Plate 6, *1-5, 8,10,12*. *15,16*). The skaergaardite-bearing sulphide grains form droplet-like (Plate 3, #*1, 3, 5-10. 16-18*; Plate 4, #*8*; Plate 6. #*3* etc) or.irregular-shaped (Plate 3, #*11,12*, *13-15* etc) aggregates. Usually skaergaardite grains are localized at the margins of sulphide globules (Plate 3, #*2-18*, *20-23*; Plate 4, #*8*; Plate 6, #*3* etc). Skaergaardite grains occur as:

1. isometric droplet-like grains with the rounded outlines (Plate 3, #*1-6, 22-34, 36*; Plate 4, #*1*; Plate5, # *1-20* etc);
2. euhedral to subhedral crystals (Plate 3, #*7-21, 39, 41-44*; Plate 4, #*7*; Plate 5, #*22-26* etc);
3. irregular grains and aggregates (Plate 3, #*37, 38, 40, 45-49*; Plate 4, #*2-6. 8, 9*; Plate 5, #*27-31* etc).

The size of skaergaardite grains is 2-93 μm with an average of 31 μm (Table 3).

Mineral chemistry

The composition of skaergaardite is constrained by 98 analyses from 98 grains (Table 6, analyses 1-98). The average composition of skaergaardite (Table 6, analysis 99) is (wt.%): Pd: 60.8, Pt: 0.8, Au: 1.2, Cu: 29.2, Fe: 4.5, Zn: 2.0, Sn: 0.3, Te: 0.3, Pb: 0.6, with a total of 99.7. The composition corresponds to the following formula:

$$(Pd_{0.98}Pt_{0.01}Au_{0.01})_{1.00}(Cu_{0.79}Fe_{0.14}Zn_{0.05}Te_{0.01}Pb_{0.01})_{1.00}.$$

Typical substitutions in skaergaardite are: Pt up to 19.8 % (Table 6, analysis 24), Au up to 17.9 % (Table 6, analysis 72), Fe up to 7.1 % (Table 6, analysis 73), Zn up to 4.9 % (Table 6, analysis 84), Sn up to 6.6 % (Table 6, analysis 26), Te up to 1.9 % (Table 6, analysis 34), Pb up to 4.2 % (Table 6, analysis 40).Pt and Au concentrations in skaergaardite (n=98) are distributed as follows (Table 7, see Table 6)

Interval, Pt wt %	Number of analyses - Pt	Interval, Au wt %	Number of analyses - Au
0-1	81	0-1	58
1-3	10	1-3	29
3-5	3	2-3	8
5-7	0	5-7	0
7-9	1	7-9	0
9-11	1	9-11	2
11-13	0	11-13	0
13-15	0	13-15	0
15-17	0	15-17	0
17-19	1	17-19	1
19-21	1	19-21	0

Table 7. Intervals of Pt and Au in skaergaardite (Sample 90-24, 1048):

Gold minerals: unnamed $(Au,Pd,Pt)_3Cu$ and tetra-auricupride (Au,Pd,Pt)(Cu,Fe)

Three grains of $(Au,Pd,Pt)_3Cu$ (possibly a variety of auricupride Au_3Cu, 1.6 vol % of precious metal minerals) and 4 grains of tetra-auricupride (1.2 vol. %) were found in heavy mineral concentrates of sample 90-24 1048 (see Table 3, Fig. 2). The gold minerals only form irregular shaped liberated grains. Grains of $(Au,Pd,Pt)_3Cu$ and tetra-auricupride occur as individual grains (Plate 7, #*1, 5*), as intergrowth with each other (Plate 7, #*4*), or in intergrowths with unnamed Pd_2Te (Plate 7, #*3, 6*). The grain size of tetra-auricupride is 4-29 µm, with an average of 19 µm. The grain size of unnamed $(Au,Pd,Pt)_3Cu$ is 20-35 µm, with an average of 26 µm. The composition of unnamed $(Au,Pd,Pt)_3Cu$ (Table 8, analyses 1-3, average in analysis 4) and tetra-auricupride (Table 8, analyses 5-8, average in analysis 9), are all close to stoikiometry $(Au,Pd,Pt)_3(Cu,Fe)$ and (Au,Pd,Pt)(Cu,Fe), respectively. Tetra-auricupride contain 11.9-16.9 % Pd with an average 14.0 % and 0-4.1 % Pt with an average 1.5 %.The unnamed phase $(Au,Pd,Pt)_3Cu$ contains 13.0-18.1 % of Pd with an average of 16.1 % and 0-2.7 % Pt with an average 0.9 %.

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

Vasilite $(Pd,Cu)_{16}S_7$ is identified analysed in five grains in the heavy mineral concentrates (1 vol. %; see Table 3 and Fig. 2). Vasilite occurs in association with chalcosine and bornite (Plate 6, #*17, 18*), and with skaergaardite (Plate 6, #*19*). It has an irregular shape (size 5-24 µm with an average 16 µm). The composition of vasilite corresponds to the stoikiometric formula $(Pd,Cu)_{16}S_7$ (Table 9, analyses 17, 18).

Unnamed Pd_2Te

Two liberated grains of the unnamed mineral phase Pd_2Te occur in an intergrowth with gold minerals – tetra-auricupride (Plate 7, #*3*) and $(Au,Pd,Pt)_3Cu$ (Plate 7, #*6*). The grain size of Pd_2Te (0.3 vo.% of all precious metal minerals) is 12-16 µm with an average 14 µm (see Table 3). Its composition deviates significantly from that of keithconite $Pd_{3-x}Te$ and telluropalladinite Pd_4Te_3. In stoichiometry it corresponds to Pd_2Te (Table 9, analyses 15, 16).

Zvyagintsevite $Pd_3(Pb,Cu,S)$, atokite $Pd_3(Sn,Cu,Pb,Te)$, (Pd,Cu,Sn) alloy, keithconite $Pd_3(Te,Cu,Pb,Sn)$

Zvyagintsevite, atokite, (Pd,Cu,Sn) alloy and keithconite are found as fine (2-12 µm) inclusions in skaergaardite grains (Plate 6, 1-16). These minerals represent a total of <1 vol.% of precious metal mineral paragenesis in the sample (see Table 3, Fig. 2). Their compositions are shown in the Table 9 (zvyagintsevite – analyses 1-8, atokite – analyses 9-12, keithconite – analysis 13 and (Pd,Cu,Sn) alloy –analysis 14).

Bulk composition of PGMs of the sample 90-24 1059

The relative concentrations of Pd, Au and Pt in sample 90-24 1048 can be calculated from the total concentration of precious metals, the recovery, the modal proportions, and the compositions of the minerals and phases (Tables 3, 6-8). The estimated bulk composition of the sample (assays of whole rock in brackets, Watts Griffis and McOuat, 2001) is (ppb): Pd 688 (630), Au 34 (52), Pt 10 (50). Pd is hosted in skaergaardite (669 ppb) and in other precious metal minerals (in total19 ppb). Pt is in skaergaardite (some in Au alloys), and Au is distributed between gold minerals (tetra-auricupride and Au_3Cu, 21ppb) and skaergaardite (13 ppb).

As noted for many of the hitherto investigated samples from the Platinova Reef, the estimates of the bulk concentration of Pt is always much lower that the assay value. As of now, no clear explanation for the discrepancy is available. Analysis of the same samples by several laboratories show not systematic deviations from the here given assay values (Watts, Griffis and McOuat, 2001) In combination with the observed but not explained fractionation of the Pd/Pt ratio in basaltic melts from the North Atlantic (Momme et al., 2003) it can not be excluded that small amounts of Pt should be found in f.ex. cumulus titanomagnetite, a phase that is not found in the described and investigated monolayer samples. Pt could be hosted in ferroplatinum as exceedingly small grains.

Discussion

PGM-paragenesis and order of crystallization

The Cu-Fe sulphides, PGMs and gold minerals were synchronous and crystallized later than liquidus minerals: plagioclase, clinopyroxene, orthopyroxene, ilmenite and titanomagnetite. Droplets of sulphide in tilmenite suggests, however, that immiscible droplet were present during the later part of the crystallization of the host rock. The characteristic droplet shape of both - PGMs and host sulphides suggest that they represent two immiscible melts: 1) Cu-Fe sulphide melt and 2) metal melt enriched in Pd, Cu, Pt and Au which has separated from the Cu-Fe melt. All our observations and the inter-grain relations (Plates 3-7) suggest that all precious metal minerals are parts of a single paragenesis.

Summary

1. 122 PGM-grains were identified in the heavy mineral concentrates of sample 90-24 1048 (1.14 kg) using hydroseparator CNT HS-11.

2. The dominant precious metal mineral of the sample is skaergaardite (Pd, Au,Pt)(Cu,Fe,Zn,Te,Pb) with 95.3 vol.%. In addition, at least 7 other PGMs (in total c. 4.7 vol.%) were identified and include: (1) unnamed $(Au,Pd,Pt)_3Cu$ (1.6 vol.%), (2) tetra-auricupride (Au,Pd,Pt)(Cu,Fe) (1.2 vol.%), (3) vasilite $(Pd,Cu)_{16}S_7$ (1.0 vol.%), (4) unnamed Pd_2Te (0.3 vol.%), (5) zvyagintsevite $Pd_3(Pb,Cu,,Sn)$ (0.2 vol.%), (6) atokite $Pd_3(Sn,Cu,Pb,Te)$ and (7) keithconite $Pd_3(Te, Cu,Pb,Sn)$, both <0.1 vol.%).

3. The estimated bulk composition of the sample (assays of whole rock in brackets) is (ppb): Pd 688 (630), Au 34 (52), Pt 10 (50). Pd is hosted in skaergaardite (669 ppb) and in other precious metal minerals (total 19 ppb). Pt is in skaergaardite (some also in Au alloys), Au is distributed between gold minerals (tetra-auricupride and Au_3Cu, 21 ppb) and skaergaardite (13 ppb).

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

5. Unnamed Pd_2Te and unnamed sulphide Cu_2FeS_3 are frequently recognized in the concentrates and may both represent naturally occurring phases and thus not yet described and named minerals.

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TABLES

Table 1. Compositions and formuli of silicates and oxides of sample 90-24 1048

Mineral	plagioclase			clinopyroxene			orthopyroxene		olivine			Ilmenite			titanomagnetite		
Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
wt%																	
SiO_2	55.9	56.7	56.5	51.5	51.6	51.2	51.5	51.3	34.5	33.9	34.3	-	-	-	-	-	-
TiO_2	-	-	-	0.3	0.4	0.3	0.2	0.2	-	-	-	51.4	50.5	52.8	14.9	12.4	11.3
Al_2O_3	27.8	27.4	27.5	1.2	1.4	1.3	0.4	-	-	-	-	-	-	-	3.7	3.7	2.5
V_2O_3	-	-	-	-	-	-	-	-	-	-	-	0.5	0.6	0.4	1.3	1.6	2.1
Fe_2O_3	-	-	-	-	-	-	-	-	-	-	-	3.9	4.8	0.6	35.6	39.9	42.6
FeO	-	-	-	13.7	12.5	12.5	26.6	29.9	45.1	45.9	46.2	42.2	40.9	45.0	43.7	41.4	41.1
MnO	-	-	-	0.3	0.4	0.3	0.6	0.7	0.8	0.6	0.5	0.6	0.7	0.4	0.2	0.5	0.2
MgO	-	-	-	12.4	12.3	12.8	18.6	16.7	20.6	19.4	19.6	1.9	2.2	1.1	1.1	1.0	0.5
CaO	-	-	-	20.2	21.1	21.2	1.7	1.0	-	-	-	-	-	-	-	-	-
Na_2O	5.9	6.2	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K_2O	0.2	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	99.5	99.3	99.7	99.8	99.7	99.7	99.8	99.8	101.0	99.8	100.6	100.5	99.6	100.3	100.4	100.5	100.2
Proportions																	
Si	2.52	2.56	2.54	1.94	1.96	1.95	1.98	1.99	1.00	1.00	1.00	-	-	-	-	-	-
Ti	-	-	-	0.01	0.01	0.01	0.01	0.01	-	-	-	0.96	0.95	0.99	0.41	0.34	0.32
Al	1.48	1.46	1.46	0.06	0.06	0.06	0.02	-	-	-	-	-	-	-	0.16	0.16	0.11
V	-	-	-	-	-	-	-	-	-	-	-	0.01	0.01	0.01	0.04	0.05	0.06
Fe^{3+}	-	-	-	-	-	-	-	-	-	-	-	0.07	0.09	0.01	0.98	1.11	1.20
Fe^{2+}	-	-	-	0.44	0.40	0.40	0.86	0.97	1.09	1.13	1.13	0.88	0.85	0.94	1.34	1.27	1.28
Mn	-	-	-	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Mg	-	-	-	0.70	0.70	0.73	1.06	0.97	0.89	0.85	0.86	0.07	0.06	0.04	0.05	0.05	0.03
Ca	0.47	0.42	0.45	0.82	0.86	0.86	0.07	0.04	-	-	-	-	-	-	-	-	-
Na	0.51	0.54	0.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K	0.01	0.02	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-
O basis	**8**	**8**	**8**	**6**	**6**	**6**	**6**	**6**	**4**	**4**	**4**	**3**	**3**	**3**	**4**	**4**	**4**

Table 2. Chemical composition and formulas of sulphides in PGM-bearing globules in the heavy mineral concentrates of sample 90-24 1048

Mineral	Bornite											Pentlandite		unnamed Cu_2FeS_3	
Grain	40 gr15	40 gr54	40 gr71	40 gr73a	40 gr73c	63 gr5	63 gr20	63 gr24	63 gr27	125 gr1	63 gr28	40 gr6	40 gr31	40 gr44	63 gr28
Association	sk+bn	sk+bn +ch	sk+bn	ch+bn	ch+bn	sk+bn	sk+bn	sk+bn	sk+bn	sk+bn +ch	sk+bn+ Cu2FeS3?	sk+zv +pn	sk+bn +ch+pn	sk+bn+ ThO2+ Cu_2FeS_3	sk+bn+ Cu_2FeS_3
Analysis	**1**	**4**	**7**	**9**	**11**	**12**	**14**	**15**	**16**	**17**	**23**	**19**	**20**	**21**	**22**
Cu	62,2	62,4	62,5	62,1	62,1	62,6	62,7	62,4	62,5	63,2	62,8	2,4	3,5	46,5	47,4
Fe	11,4	11,1	11,7	12,0	11,7	11,2	11,6	11,7	11,4	11,2	11,3	10,2	15,3	21,4	21,8
Ni	-	-	-	-	-	-	-	-	-	-	-	30,8	36,8	-	-
Co	-	-	-	-	-	-	-	-	-	-	-	23,3	11,3	-	-
S	25,8	26,1	25,0	24,9	25,1	25,6	26,2	25,3	25,7	24,5	23,5	32,7	32,3	31,5	30,4
Total	99,4	99,6	99,2	99,0	98,9	99,4	100,5	99,4	99,6	99,0	99,6	99,4	99,2	99,4	99,6
Proportions															
Cu	4,92	4,99	4,99	4,96	4,96	4,96	4,90	4,96	4,94	5,07	4,98	0,30	0,44	2,09	2,15
Fe	1,03	1,00	1,06	1,09	1,06	1,01	1,04	1,06	1,03	1,02	1,02	1,44	2,15	1,1	1,12
Ni	-	-	-	-	-	-	-	-	-	-	-	4,13	4,94	-	-
Co	-	-	-	-	-	-	-	-	-	-	-	3,11	1,01	-	-
S	4,05	4,07	3,95	3,94	3,97	4,02	4,07	3,98	4,03	3,90	4	8,03	7,95	2,81	2,73
Total	10	10	10	10	10	10	10	10	10	10	10	17	17	6	6

Abbreviations bn: bornite; ch: chalcocine; pn: pentlandite; $CuFe_2S_3$: unnamed mineral

Table 2. Continued

Mineral	Chalcocine							
Grain	40 gr47	40 gr16a	40 gr54	40 gr70a	40 gr73a	40 gr73c	63 gr15	125 gr1
Association	vs+ch	ch+bn	sk+bn +ch	ch+bn	ch+bn	ch+bn	sk+ch	sk+bn +ch
Analysis	**3**	**2**	**5**	**6**	**8**	**10**	**13**	**18**
Cu	79,2	78,1	79,7	77,9	77,7	77,5	78,0	76,5
Fe	-	1,0	1,2	1,4	1,3	1,7	1,5	0,8
Ni	-	-	-	-	-	-	-	-
Co	-	-	-	-	-	-	-	-
S	19,9	20,2	20,5	20,5	20,1	20,0	21,1	20,0
Total	99,1	99,3	101,4	99,8	99,1	99,2	100,5	99,3
Proportions								
Cu	2,00	1,96	1,96	1,94	1,96	1,95	1,92	1,98
Fe	-	0,03	0,03	0,04	0,04	0,05	0,04	0,02
Ni	-	-	-	-	-	-	-	-
Co	-	-	-	-	-	-	-	-
S	1,00	1,01	1,00	1,02	1,00	1,00	1,03	1,00
Total	3	3	3	3	3	3	3	3

Abbreviations bn: bornite; ch: chalcocine; pn: pentlandite; $CuFe_2S_3$: unnamed mineral

Table 3. Precious metal minerals in heavy mineral concentrates of sample 90-24 1048

Mineral	General formula	Number of grains	Grain size, µm min	max	av.	Vol. %
Skaergaardite	(Pd,Au,Pt)(Cu,Fe,Zn)	110	2	93	31	95,3
Unnamed	$(Au,Pd,Pt)_3(Cu,Fe)$	3	20	35	26	1,6
Tetra-auricupride	(Au,Pd,Pt)(Cu,Fe)	4	4	29	19	1,2
Vasilite	$(Pd,Cu)_{16}S_7$	5	5	24	16	1
Unnamed	Pd_2Te	2	12	16	14	0,3
Zvyagintsevite	Pd_3 (Pb,Cu,Sn)	9	3	8	6	0,2
Atokite	$Pd_3(Sn,Cu,Pb,Te)$	6	2	12	7	0,3
Keithconite	$Pd_3(Te,Cu,Pb,Sn)$	3	2	7	4	<0,1

Table 4 Grain sizes of precious metal minerals in the heavy mineral concentrates of sample 90-24 1048

N	Gr#	host/association	Assoc. type	Mineral	Area µm^2	ECD, µm
1	40-11	sk	L	sk	423	23
2	40-12	sk	L	sk	1107	38
3	40-13	sk	L	sk	702	30
4	40-14	sk	L	sk	911	34
5	40-15	sk+bn	bms-L	sk	970	35
6	40-16	sk	L	sk	381	22
7	40-17	sk+ilm	ag-L	sk	218	17
8	40-18	sk+bn	bms	sk	42	7
9	40-19	sk+vs	L+	total	1088	37
10	40-19	sk+vs	L+	sk	880	33
11	40-19	sk+vs	L+	vs	208	16
12	40-1	sk+bn+pn	bms-L	sk	517	26
13	40-20	sk	L	sk	245	18
14	40-21	sk+zv	L+	total	569	27
15	40-21	sk+zv	L+	sk	543	26
16	40-21	sk+zv	L+	zv	26	6
17	40-22	sk+bn+ch	bms-L	sk	556	27
18	40-23	sk+bn	bms-L	sk	1169	39
19	40-24	Au_3Cu+Pd_2Te	L+	total	523	26
20	40-24	Au_3Cu+Pd_2Te	L+	Au_3Cu	327	20
21	40-24	Au_3Cu+Pd_2Te	L+	Pd_2Te	196	16
22	40-25	sk	L	sk	1302	41
23	40-26	sk	L	sk	659	29
24	40-27	sk	L	sk	813	32
25	40-28	sk	L	sk	467	24
26	40-29	sk+bn+ch+chl	sag-L	sk	637	28
27	40-2	sk+bn+ch	bms	sk	2	2
28	40-30	sk+at+ilm	ag-L+	total	868	33
29	40-30	sk+at+ilm	ag-L+	sk	772	31
30	40-30	sk+at+ilm	ag-L+	at	90	11
31	40-30	sk+at+ilm	ag-L+	at	6	3
32	40-31	sk+bn+ch+pn	bms	sk	88	11
33	40-32	sk+bn	bms	sk	967	35
34	40-33	sk+(Pd,Cu,Sn)	L+	total	435	24
35	40-33	sk+(Pd,Cu,Sn)	L+	sk	433	23
36	40-33	sk+(Pd,Cu,Sn)	L+	(Pd,Cu,Sn)	2	2
37	40-34	sk	L	sk	504	25
38	40-35	sk	L	sk	476	25
39	40-37	sk	L	sk	573	27
40	40-38	Au_3Cu	L	Au_3Cu	938	35
41	40-39	sk	L	sk	1134	38
42	40-3	Au_3Cu+AuCu	L+	total	486	25
43	40-3	Au_3Cu+AuCu	L+	Au_3Cu	476	25
44	40-3	Au_3Cu+AuCu	L+	AuCu	10	4
45	40-40	sk+zv	L+	Total	947	35
46	40-40	sk+zv	L+	sk	929	34
47	40-40	sk+zv	L+	zv	18	5
48	40-41	sk+bn	bms	sk	853	33
49	49-42	sk+ch	bms-L	sk	678	29
50	40-43	AuCu	L	AuCu	257	18
51	40-44	sk+bn+Cu_2FeS_3+ThO2	bms	sk	552	27
52	40-45	sk	L	sk	570	27
53	40-46	sk	L	sk	1063	37
54	40-47	vs+ch	bms	vs	456	24
55	40-47	vs+ch	bms	vs	240	17
56	40-47	vs+ch	bms	vs	17	5
57	40-48	sk+zv+bn+ch	bms+	total	772	31
58	40-48	sk+zv+bn+ch	bms+	zv	18	5
59	40-48	sk+zv+bn+ch	bms+	sk	754	31

Table 4 continued

N	Gr#	host/association	Assoc. type	Mineral	Area μm^2	ECD, μm
60	40-49	sk	L	sk	740	31
61	40-4	sk+bn+ch	bms	sk	260	18
62	40-50	sk+bn+ch	bms	sk	41	7
63	40-51	sk	L	sk	1860	49
64	40-52	sk+bn+ilm	sag-L	sk	315	20
65	40-53	sk	L	sk	84	10
66	40-54	sk+bn+ch	bms	sk	110	12
67	40-55	sk	L	sk	370	22
68	40-56	sk	L	sk	291	19
69	40-57	sk+zv	L+	total	810	32
70	40-57	sk+zv	L+	zv	27	6
71	40-57	sk+zv	L+	sk	783	32
72	40-58	sk_bn+ch	bms	sk	112	12
73	40-59	sk+at+bn	bms-L+	total	546	26
74	40-59	sk+at+bn	bms-L+	at	36	7
75	40-59	sk+at+bn	bms-L+	sk	510	25
76	40-5	sk+bn	bms-L	sk	1330	41
77	40-60	sk+zv+bn	bms-L+	Total	1126	38
78	40-60	sk+zv+bn	bms-L+	sk	1094	37
79	40-60	sk+zv+bn	bms-L+	zv	32	6
80	40-61	sk+bn+ch	bms	sk	7	3
81	40-62	sk	L	sk	196	16
82	40-63	AuCu+Pd_2Te	L+	total	785	32
83	40-63	AuCu+Pd_2Te	L+	AuCu	671	29
84	40-63	AuCu+Pd_2Te	L+	Pd_2Te	114	12
85	40-64	sk+at+bn	bms+	total	981	35
86	40-64	sk+at+bn	bms+	sk	881	34
87	40-64	sk+at+bn	bms+	at	100	11
88	40-65	sk+bn	bms-L	sk	869	33
89	40-66	sk+bn+ol	sag-L	sk	765	31
90	40-67	sk	L	sk	1604	45
91	40-68	sk	L	sk	141	13
92	40-69	sk+bn+ch	bms	sk	219	17
93	40-6	sk+zv+pn	bms-L+	total	1041	36
94	40-6	sk+zv+pn	bms-L+	sk	996	36
95	40-6	sk+zv+pn	bms-L+	zv	45	8
96	40-70	sk+bn+ch	bms	sk	142	13
97	40-71	sk+bn	bms-L	sk	643	29
98	40-72	sk+bn+ch	bms-	sk	637	28
99	40-73	sk+bn+ch	bms	sk	420	23
100	40-7	sk+bn+ch	bms	sk	2	2
101	40-7	sk+bn+ch	bms	sk	7	3
102	40-8	AuCu	L	AuCu	450	24
103	40-9	sk+zv+bn	bms-L+	total	663	29
104	40-9	sk+zv+bn	bms-L+	sk	634	28
105	40-9	sk+zv+bn	bms-L+	zv	29	6
106	63-10	sk+bn+pn	bms	sk	891	34
107	63-11	sk+pn	bms-L	sk	1989	50
108	63-12	sk+bn	bms-L	sk	4015	72
109	63-13	sk+bn+ch	bms	sk	153	14
110	63-14	sk	L	sk	2037	51
111	63-15	sk+ch	bms	sk	2561	57
112	63-16	sk+opx	ag-L	sk	2078	51
113	63-17	sk+zv+ch+bn	bms+	total	1490	44
114	63-17	sk+zv+ch+bn	bms+	sk	1441	43
115	63-17	sk+zv+ch+bn	bms+	zv	49	8
116	63-18	sk+cp+bn	bms	sk	2255	54
117	63-19	sk+zv+bn+ch	bms+	total	197	16
118	63-19	sk+zv+bn+ch	bms+	zv	7	3
120	63-19	sk+zv+bn+ch	bms+	sk	190	16
121	63-1	sk+at	L+	total	1536	44
122	63-1	sk+at	L+	sk	1431	43
123	63-1	sk+at	L+	at	105	12

Table 4 continued

N	Gr#	host/association	Assoc. type	Mineral	Area μm^2	ECD, µm
124	63-20	sk+bn	bms	sk	1538	44
125	63-21	sk+bn+ch	bms	sk	598	28
126	63-22	sk+bn	bms-L	sk	2252	54
127	63-23	sk	L	sk	3901	70
128	63-24	sk+bn	bms	sk	1711	47
129	63-25	sk+bn+chl	sag	sk	109	12
130	63-26	sk+bn+pl	sag	sk	1850	49
131	63-27	sk+bn	bms	sk	1338	41
132	63-28	sk+bn+Cu_2FeS_3	bms	sk	159	14
133	63-2	sk+bn	bms	sk	217	17
134	63-3	sk+bn	bms	sk	2003	51
135	63-4	sk+bn	bms-L	sk	959	35
136	63-5	sk+bn	bms	sk	1051	37
137	63-6	sk+kth+bn	bms+	total	373	22
138	63-6	sk+kth+bn	bms+	kth	3	2
139	63-6	sk+kth+bn	bms+	kth	5	3
140	63-6	sk+kth+bn	bms+	sk	365	22
141	63-7	sk	L	sk	848	33
142	63-8	sk	L	sk	1831	48
143	63-9	sk	L	sk	2039	51
144	80-10	sk+bn+pn	bms	sk	921	34
145	80-11	sk+kth+bn+ch	bms+	total	259	18
146	80-11	sk+kth+bn+ch	bms+	kth	35	7
147	80-11	sk+kth+bn+ch	bms+	sk	224	17
148	80-11	sk+kth+bn+ch	bms+	sk	8	3
149	80-11	sk+kth+bn+ch	bms+	sk	7	3
150	80-12	sk	L	sk	1860	49
151	80-13	sk+bn	bms-L	sk	5853	86
152	80-1	sk+bn	bms-L	sk	3814	70
153	80-2	sk+bn	bms	sk	368	22
154	80-3	sk+bn	bms	sk	1500	44
155	80-4	sk	L	sk	1928	50
156	80-5	sk+bn+ch	bms	sk	901	34
157	80-5	sk+bn+ch	bms	sk	26	6
158	80-6	sk+bn+ch	bms	sk	43	7
159	80-7	sk+bn+ch+chl	sag	sk	5	3
160	60-8	vs+bn	bms	vs	240	17
161	80-9	sk+bn+ch	bms	sk	172	15
162	125-1	sk+bn+ch	bms	sk	1610	45
163	125-2	sk+bn	bms-L	sk	6788	93

Abbreviations:

Silicates	chl: chlorite; ol: olivine; opx:orthopyroxene
FeTi oxides	ilm: ilmenite;
others:	ThO_2: torianite
sulphides	bn: bornite; pentlandite; ch: chalcocine; cp: chalcopyrite; Cu_2FeS_3: unnamed sulphide;
PGMs	sk: skaergaardite; vs: vasilite, zv:zyagintsevite; Au3Cu: auricupride; Pd2Te: unnamed alloy;
	at: atokite; kth: keithconite; (Pd,Cu,Sn):unnamed alloy; AuCu: tetra-auricupride; Pd_2Te: unnamed alloy;

Associations:

bms-L	liberated particles with <10 % attached base metal sulphides
bms	intergrowths with base metal sulphides (bornite, chalcosine, pentlandite, unnamed Cu2FeS3?)
L	completely liberated (free) particles;
sag	sulphide and gangue (pyroxenes, plagioclase, ilmenie, olivine, chlorite, calcite, thorianite) attached to PGMs
bms+	more precious metal phases attached to base metal phases
L+	more than one precious metal minerals completely liberated (free) particles,
ag-L	liberated particles with <10% attached gauge
bms-L+	more than one liberated particles of precious metal phases with <10 % attached base metal sulphides

Table 5

Enclosed in text

Table 6 Chemical composition and formula of skaergaardite in PGM grains in the heavy mineral concentrates of sample 90- 24 1048

Analysis#	1	2	3	4	5	6	7	8	9	10	11	12	13
Grain	40 gr1	40 gr4	40 gr5	40 gr6	40 gr9	40 gr10	40 gr11	40 gr12	40 gr13	40 gr14	40 gr15	40 gr16	40 gr17
Association	sk+bn +ch	sk+bn +ch	sk+bn	sk+zv +pn	sk+zv +bn	sk	sk	sk	sk	sk	sk	sk+bn	sk+ilm
Analysis wt%													
Pd	62.7	61.2	62.7	64.1	61.3	59.1	63.1	62.0	64.1	60.5	63.3	62.5	59.0
Pt	0.0	1.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Au	0.0	2.2	0.0	0.0	2.5	2.1	0.0	0.0	0.0	2.8	0.0	0.0	4.7
Cu	29.0	28.8	29.7	30.0	27.4	28.5	28.5	28.9	28.1	28.4	28.0	28.6	30.3
Fe	5.1	4.6	6.6	4.1	4.7	4.7	4.6	4.8	4.7	4.4	5.9	4.4	3.4
Zn	2.5	1.1	0.4	2.3	2.6	1.9	2.1	1.5	2.5	1.6	2.4	3.2	0.9
Sn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Te	0.0	0.5	0.0	0.0	0.9	1.1	0.0	0.0	0.0	1.6	0.0	0.6	1.5
Pb	0.0	0.0	0.0	0.0	0.0	1.4	1.4	1.2	0.0	0.9	0.0	0.0	0.0
Total	99.3	99.7	99.4	100.5	99.4	99.8	99.8	99.4	99.5	99.9	99.6	99.4	99.8
Proportions													
Pd	1.00	0.82	1.00	1.02	1.00	0.97	1.02	1.00	1.03	0.99	1.01	1.00	0.97
Pt	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Au	0.00	0.02	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.04
Cu	0.78	0.79	0.79	0.80	0.75	0.78	0.77	0.78	0.76	0.77	0.75	0.77	0.83
Fe	0.15	0.14	0.20	0.12	0.15	0.15	0.14	0.15	0.14	0.14	0.18	0.14	0.11
Zn	0.07	0.03	0.01	0.06	0.07	0.05	0.06	0.04	0.07	0.04	0.06	0.08	0.02
Sn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Te	0.00	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.03	0.00	0.01	0.03
Pb	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o.: ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite

Base metal sulphides: bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed

PGMs: sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 6 continued

Analysis#	14	15	16	17	18	19	20	21	22	23	24	25	26
Grain	40 gr18	40 gr19	40 gr21	40 gr23	40 gr25	40 gr26	40 gr27	40 gr28	40 gr29	40 gr30	40 gr31	40 gr32	40 gr33
Association	sk+bn	sk+vs	sk+zv	sk+bn	sk	sk	sk	sk	sk+bn+	sk+ilm+	sk+bn+	sk+bn	sk+
									ch+chl	(Pd,Sn,Cu)	ch+pn		(Pd,Cu,Sn)
Analysis wt%													
Pd	56.2	63.3	60.0	63.1	62.6	62.4	61.7	62.3	63.1	59.9	44.4	61.5	60.7
Pt	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	19.8	0.0	0.0
Au	3.4	0.0	3.1	0.0	0.0	1.0	1.7	0.0	0.0	1.3	2.1	0.0	0.0
Cu	29.1	29.3	28.7	29.7	28.9	30.4	29.0	28.7	31.0	28.8	26.8	30.3	30.1
Fe	4.9	5.2	4.3	3.9	6.0	3.5	4.5	5.7	5.8	3.0	5.8	3.1	1.4
Zn	1.4	2.0	2.5	2.4	1.8	2.5	2.8	2.0	0.0	1.3	0.9	1.4	0.7
Sn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	2.3	0.0	1.2	6.6
Te	0.9	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pb	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	2.4	0.0	2.1	0.0
Total	99.6	99.8	99.3	100.0	99.3	99.8	99.7	99.3	99.9	100.0	99.8	99.7	99.5
Proportions													
Pd	0.93	1.01	0.98	1.01	1.00	1.00	0.99	1.00	1.00	0.99	0.78	1.00	1.00
Pt	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.19	0.00	0.00
Au	0.03	0.00	0.03	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.00	0.00
Cu	0.80	0.78	0.78	0.80	0.77	0.82	0.78	0.77	0.82	0.80	0.79	0.83	0.84
Fe	0.15	0.16	0.13	0.12	0.18	0.11	0.14	0.17	0.18	0.10	0.19	0.10	0.04
Zn	0.04	0.05	0.07	0.06	0.05	0.07	0.07	0.05	0.00	0.04	0.03	0.04	0.02
Sn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.02	0.10
Te	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o.: ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite

Base metal sulphides: bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed

PGMs: sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 6 continued

Analysis#	27	28	29	30	31	32	33	34	35	36	37	38	39
Grain	40 gr34	40 gr35	40 gr36	40 gr37	40 gr39	40 gr40	40 gr41	40 gr42	40 gr44	40 gr45	40 gr46	40 gr48	40 gr49
Association	sk	sk	sk	sk	sk	sk+zv	sk+bn	sk+ch	sk+bn+ $FeCu_2S_3$ +ThO_2	sk	sk	sk+zv +bn+ch	sk
Analysis wt%													
Pd	62.5	61.4	61.8	62.6	63.2	62.7	61.6	58.4	63.1	62.6	59.9	60.7	59.4
Pt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Au	0.0	1.1	1.5	0.0	0.0	0.0	1.2	3.3	0.0	0.0	4.0	2.1	3.4
Cu	29.3	30.1	29.3	29.3	28.9	29.5	28.2	27.7	30.6	30.0	29.4	29.7	28.1
Fe	3.8	2.5	3.9	4.2	5.0	3.2	5.2	3.5	3.8	6.6	3.8	3.3	4.0
Zn	2.5	2.2	2.5	3.0	2.7	2.2	2.5	3.3	2.6	0.0	2.1	2.9	3.0
Sn	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Te	0.7	1.1	1.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	1.0	1.1	0.6
Pb	1.7	2.6	1.0	1.1	0.0	1.9	1.0	1.0	0.0	0.0	0.0	0.0	1.1
Total	100.5	101.0	101.0	100.2	99.8	100.6	99.7	100.1	100.2	99.2	100.2	99.9	99.6
Proportions													
Pd	1.00	1.00	0.99	1.00	1.01	1.01	0.99	0.96	1.00	1.00	0.97	0.98	0.97
Pt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Au	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.04	0.02	0.03
Cu	0.79	0.82	0.79	0.78	0.77	0.80	0.76	0.76	0.81	0.80	0.80	0.80	0.77
Fe	0.12	0.08	0.12	0.13	0.15	0.10	0.16	0.11	0.12	0.20	0.12	0.10	0.13
Zn	0.07	0.06	0.05	0.08	0.07	0.06	0.07	0.09	0.07	0.00	0.06	0.08	0.08
Sn	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Te	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.02	0.02	0.01
Pb	0.01	0.02	0.01	0.01	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.01
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o.: ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite

Base metal sulphides: bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed

PGMs: sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 6 continued

Analysis#	40	41	42	43	44	45	46	47	48	49	50	51	52
Grain	40 gr50	40 gr51	40 gr52	40 gr 54	40 gr55	40 gr56	40 gr57	40 gr58	40 gr59	40 gr60	40 gr64	40 gr65	40 gr66
Association	sk+bn +ch	sk	sk+bn +ilm	sk+bn +ch	sk	sk	sk+zv	sk+bn +ch	sk+at +bn	sk+zv +bn	sk+bn+ (Pd,Cu,Sn)	sk+bn	sk+bn +ol
Analysis wt%													
Pd	52.9	61.7	61.2	62.3	58.8	59.8	61.6	45.8	61.7	63.2	60.3	62.7	62.0
Pt	4.8	0.0	0.0	0.0	1.3	1.0	0	18.5	0	0.0	1.3	0.0	0.0
Au	1.8	0.0	1.9	0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Cu	31.1	29.6	27.9	30.2	30.2	30.2	29.4	27.5	29.1	29.7	28.9	28.0	29.8
Fe	2.2	4.6	5.2	2.7	5.0	2.9	4.1	6.4	3.9	4.8	3.4	6.9	3.8
Zn	1.8	1.9	2.7	2.2	0.6	0.9	2.6	0.9	1.9	2.8	2.2	2.2	2.8
Sn	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	1.1	0.0	0.7	0.0	0.0
Te	0.0	0.0	0.7	0.0	1.0	0.0	0.0	0.0	0.5	0.0	0.6	0.0	0.5
Pb	4.2	1.4	0.0	1.2	1.2	1.9	1.3	0.0	1.8	0.0	2.0	0.0	0.0
Total	99.0	99.2	99.6	100.5	100.1	99.5	99.0	99.0	100.0	100.4	99.4	99.8	99.9
Proportions													
Pd	0.90	1.00	0.99	1.01	0.95	0.99	1.00	0.79	1.00	1.00	0.99	0.99	0.99
Pt	0.05	0.00	0.00	0.00	0.01	0.01	0.00	0.18	0.00	0.00	0.01	0.00	0.00
Au	0.02	0.00	0.02	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Cu	0.88	0.80	0.75	0.82	0.82	0.84	0.80	0.80	0.79	0.79	0.79	0.74	0.80
Fe	0.07	0.14	0.16	0.08	0.15	0.09	0.13	0.21	0.12	0.14	0.11	0.21	0.12
Zn	0.05	0.05	0.07	0.06	0.02	0.02	0.07	0.03	0.05	0.07	0.06	0.06	0.07
Sn	0.00	0.00	0.00	0.02	0.00	0.03	0.00	0.00	0.02	0.00	0.01	0.00	0.00
Te	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01
Pb	0.04	0.01	0.00	0.01	0.01	0.02	0.01	0.00	0.01	0.00	0.02	0.00	0.00
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o: ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite

Base metal sulphides: bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed

PGMs: sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 6 continued

Analysis#	53	54	55	56	57	58	59	60	61	62	63	64	65
Grain	40 gr67	40 gr68	40 gr69	40 gr70	40 gr71	40 gr72	40 gr73	63 gr1	63 gr2	63 gr3	63 gr4	63 gr5	63 gr6
Association	sk	sk	sk+ch +bn	sk+bn +ch	sk+bn	sk+bn +ch	sk+bn +ch	sk+at	sk+bn	sk+bn	sk+bn	sk+bn	sk+kth +bn
Analysis wt%													
Pd	59.3	50.1	60.4	61.0	54.1	61.7	61.5	61.7	61.0	62.7	61.2	61.5	52.3
Pt	1.1	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
Au	1.9	3.0	0.0	0.0	9.7	0.0	0.0	0.0	1.3	0.0	1.3	1.3	10.6
Cu	28.9	25.8	30.8	28.7	30.5	27.9	29.8	29.4	28.7	29.3	29.7	29.6	31.7
Fe	5.6	6.2	3.3	2.9	2.3	4.0	4.5	4.3	4.8	5.1	5.0	3.7	1.3
Zn	0.3	1.9	1.0	2.2	2.1	2.6	3.2	1.3	3.4	1.8	2.4	2.2	2.2
Sn	0.0	0.0	1.8	1.0	0.0	1.0	0.0	2.0	0.0	0.6	0.0	0.0	0.0
Te	1.8	0.0	0.5	0.5	1.2	0.6	0.0	0.0	0.7	0.0	0.0	0.8	1.1
Pb	1.0	1.8	1.9	2.8	0.0	1.4	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Total	99.9	99.4	99.7	99.1	99.9	99.2	99.0	99.7	99.0	99.5	99.6	99.1	100.1
Proportions													
Pd	0.96	0.86	0.98	1.01	0.91	1.01	0.98	1.00	0.97	1.00	0.98	1.00	0.88
Pt	0.01	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Au	0.02	0.03	0.00	0.00	0.09	0.00	0.00	0.03	0.01	0.00	0.01	0.01	0.10
Cu	0.79	0.74	0.84	0.79	0.85	0.76	0.80	0.80	0.77	0.79	0.80	0.81	0.89
Fe	0.17	0.20	0.10	0.09	0.07	0.12	0.14	0.13	0.15	0.15	0.15	0.11	0.04
Zn	0.01	0.05	0.03	0.06	0.06	0.07	0.08	0.03	0.09	0.05	0.06	0.06	0.06
Sn	0.00	0.00	0.03	0.02	0.00	0.02	0.00	0.03	0.00	0.01	0.00	0.00	0.00
Te	0.03	0.00	0.01	0.01	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.02
Pb	0.01	0.02	0.02	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o.: ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite

Base metal sulphides: bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed

PGMs: sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 6 continued

Analysis#	66	67	68	69	70	71	72	73	74	75	76	77	78
Grain	63 gr7	63 gr8	63 gr9	63 gr10	63 gr11	63 gr12	63 gr13	63 gr14	63 gr15	63 gr16	63 gr17	63 gr18	63 gr19
Association	sk	sk	sk	sk+zv +bn+pn	sk+pn	sk+bn	sk+bn +ch	sk	sk+ch	sk+opx	sk+bn +ch	sk+bn +cp	sk+zv +bn+ch
Analysis wt%													
Pd	60.0	63.9	63.2	62.6	61.9	63.1	44.1	61.9	63.5	61.4	62.8	62.6	61.4
Pt	0.0	0.0	0.0	0.0	9.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Au	4.2	0.0	0.0	0.0	1.0	0.0	17.9	0.0	0.0	0.0	1.7	0.0	1.0
Cu	29.3	28.7	29.0	29.8	30.4	29.3	31.2	28.9	27.9	28.6	29.9	29.5	30.0
Fe	4.4	5.8	5.7	4.4	5.2	5.6	1.8	7.1	6.2	5.3	4.2	5.5	2.1
Zn	1.6	2.4	2.0	2.6	0.6	1.8	0.0	0.0	0.7	1.6	2.1	1.9	4.1
Sn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0
Te	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.7	0.0	0.0	0.0	0.0	0.0
Pb	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	1.2	0.0	0.0	1.4
Total	100.5	100.8	99.9	99.1	99.1	99.8	100.0	99.6	100.3	99.5	100.7	99.5	100.0
Proportions													
Pd	0.97	1.01	1.01	1.00	1.00	1.00	0.78	0.99	1.00	0.99	1.00	1.00	0.99
Pt	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Au	0.04	0.00	0.00	0.00	0.01	0.00	0.17	0.00	0.00	0.00	0.01	0.00	0.00
Cu	0.80	0.76	0.77	0.80	0.82	0.78	0.93	0.77	0.79	0.77	0.80	0.79	0.81
Fe	0.14	0.17	0.17	0.13	0.16	0.17	0.05	0.21	0.19	0.16	0.13	0.17	0.07
Zn	0.04	0.06	0.00	0.07	0.02	0.05	0.00	0.00	0.02	0.04	0.06	0.05	0.11
Sn	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Te	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00
Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o.: ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite

Base metal sulphides: bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed

PGMs: sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 6 continued

Analysis#	79	80	81	82	83	84	85	86	87	89	90	91	92
Grain	63 gr20	63 gr21	63 gr22	63 gr23	63 gr24	63 gr25	63 gr26	63 gr27	63 gr28	80 gr1	80 gr2	80 gr3	80 gr4
Association	sk+bn	sk+bn +ch	sk+bn	sk	sk+bn	sk+bn +chl	sk+bn +pl	sk+bn	sk+bn+ Cu_2FeS_3	sk+bn	sk+bn	sk+bn	sk
Analysis wt%													
Pd	62.0	61.2	62.3	62.4	62.9	61.4	63.2	62.9	63.4	62.7	62.2	62.4	60.2
Pt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Au	0.0	1.9	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	1.5
Cu	29.3	29.9	29.0	28.1	30.0	28.6	29.4	28.1	29.2	29.4	29.4	29.6	29.3
Fe	5.0	3.4	6.0	6.1	6.4	2.2	6.2	5.4	3.1	6.1	4.2	5.5	4.4
Zn	1.5	2.6	2.2	1.8	0.0	4.9	0.7	2.6	3.9	1.7	3.5	1.9	1.9
Sn	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	1.0
Te	0.0	0.6	0.0	0.0	0.0	0.0	1.0	0	0.0	0.0	0.0	0.0	0.0
Pb	0.0	0.0	0.0	1.2	0.0	1.2	0.0	0	0.0	0.0	0.0	0.0	1.4
Total	99.4	99.6	99.5	99.6	99.3	100.4	99.9	99.1	99.6	99.9	99.4	99.5	99.7
Proportions													
Pd	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.02	0.99	0.99	0.99	0.98
Pt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Au	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Cu	0.79	0.81	0.77	0.76	0.80	0.78	0.79	0.76	0.79	0.78	0.79	0.79	0.80
Fe	0.15	0.10	0.18	0.19	0.20	0.07	0.19	0.16	0.09	0.18	0.13	0.17	0.14
Zn	0.04	0.07	0.06	0.05	0.00	0.13	0.02	0.07	0.10	0.04	0.09	0.05	0.05
Sn	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02
Te	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o.: ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite
Base metal sulphides: bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed
PGMs: sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 6 continued

Analysis#	93	94	95	96	97	98	99
Grain	80 gr7	80 gr10	80 gr12	80 gr13	125 gr1	125 gr2	
Association	sk+bn+ ch+chl	sk+bn +pn	sk	sk+bn	sk+bn +ch	sk+bn	avr
Analysis wt%							
Pd	57.4	60.5	62.3	62.4	62.8	62.1	60.8
Pt	3.6	0.0	0.0	0.0	0.0	0.0	0.8
Au	1.4	0.0	1.2	0.0	0.0	0.0	1.2
Cu	29.6	29.0	30.1	29.8	29.9	29.5	29.2
Fe	4.2	4.5	4.5	7.0	4.4	6.2	4.5
Zn	1.7	2.4	1.6	0.0	2.5	1.8	2.0
Sn	0.0	1.0	0.0	0.0	0.0	0.0	0.3
Te	0.8	0.0	0.0	0.0	0.7	0.0	0.3
Pb	1.4	1.9	0.0	0.0	0.0	0.0	0.6
Total	99.9	99.3	99.7	99.2	100.4	99.6	99.7
Proportions							
Pd	0.94	0.98	1.00	0.99	1.00	0.98	0.98
Pt	0.03	0.00	0.00	0.00	0.00	0.00	0.01
Au	0.01	0.00	0.01	0.00	0.00	0.00	0.01
Cu	0.81	0.79	0.81	0.80	0.80	0.78	0.79
Fe	0.13	0.14	0.14	0.21	0.13	0.19	0.14
Zn	0.05	0.06	0.04	0.00	0.06	0.05	0.05
Sn	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Te	0.01	0.00	0.00	0.00	0.01	0.00	0.01
Pb	0.01	0.02	0.00	0.00	0.00	0.00	0.01
Total	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Abbreviations:

Silicates, FeTi-oxides a.o.:	ol: olivine; opx: orthopyroxene; ilm: ilmenite; chl: chlorite; ThO_2: torianite
Base metal sulphides:	bn: bornite; ch: chalcocine; pn: pentlandite; Cu_2FeS_3: unnamed; $FeCu_2S_3$: unnamed
PGMs:	sk: skaergaardite; zv: zvyangintsevite; vs: vasilite;at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy

Table 7

Enclosed in text

Table 8 Composition and formuli of Pd-bearing gold minerals in the heavy mineral concentrates of sample 90-24 1048

mineral	**Au_3Cu**				**AuCu**				
Grain #	40 gr3	40 gr24	40 gr38	avr	40 gr3	40 gr8	40 gr43	40 gr63	avr
Association	Au_3Cu+AuCu	Au_3Cu+kth	Au_3Cu		Au_3Cu+AuCu	AuCu	AuCu	AuCu	
An.	1	2	3	4	5	6	7	8	9
Analysis									
wt%									
Au	68,1	75,3	69,8	71,1	56,3	60,2	55,0	59,1	57,7
Pd	17,2	13,0	18,1	16,1	16,9	11,9	13,1	14,0	14,0
Pt	2,7	0,0	0,0	0,9	1,7	0,0	4,1	0,0	1,5
Cu	10,9	11,5	11,1	11,2	22,6	26,8	25,6	26,8	25,5
Fe	0,9	0,0	0,6	0,5	1,1	0,0	1,8	0,0	0,7
Te	0,0	0,0	0,0	-	0,0	0,8	0,0	0,0	0,2
Pb	0,0	0,0	0,0	-	1,3	0,0	0,0	0,0	0,3
Total	99,9	99,8	99,6	99,8	99,9	99,7	99,6	99,9	99,9
Proportions									
Au	1,95	2,23	2,00	2,06	0,68	0,72	0,65	0,70	0,69
Pd	0,91	0,71	0,96	0,86	0,38	0,26	0,29	0,31	0,31
Pt	0,08	0,00	0,00	0,03	0,02	0,00	0,05	0,00	0,02
Cu	0,97	1,06	0,98	1,00	0,85	1,00	0,94	0,99	0,95
Fe	0,09	0,00	0,05	0,05	0,05	0,00	0,07	0,00	0,03
Te	0,00	0,00	0,00	-	0,00	0,02	0,00	0,00	0,01
Pb	0,00	0,00	0,00	-	0,02	0,00	0,00	0,00	0,01
Total	4,00	4,00	4,00	4,00	2,00	2,00	2,00	2,00	2,00

Abbreviations: Au_3Cu: Auricupride; AuCu: tetra-auricupride; kth: keithconite

Table 8 **Compositions and formuli of the Pd, Cu, Te alloys zvyagintsevite, atokite and keithconite, vasilite, (Pd,Cu,Sn) alloy and unnamed Pd_2Te in the heavy mineral concentrates of sample 90-24 1048**

Mineral	zvyagintsevite								Atokite?	atokite		
Grain	40 gr6	40 gr9	40 gr21	40 gr48	40 gr57	40 gr60	63 gr10	63 gr17	40 gr40	40 gr30	40 gr59	63 gr1
Association	sk+zv +pn	sk+zv +bn	sk+zv	sk+zv +bn+ch	sk+zv	sk+zv +bn	sk+zv +bn+pn	sk+zv +bn+ch	sk+at	sk+at +ilm	sk+at +bn	sk+at
Analysis	1	2	3	4	5	6	7	8	9	10	11	12
wt%												
Pd	71,0	67,2	69,6	68,5	61,3	71,8	73,8	65,8	69,3	67,0	72,0	70,1
Cu	1,7	1,7	3,3	2,2	1,5	1,0	4,0	1,7	5,0	10,5	2,5	2,9
Fe	0,5	1,0	0,6	0,4	0,6	1,3	0,9		1,0	0,6	0,7	0,9
Sn	3,3	2,4	3,5			2,3	6,9	2,1	8,3	21,9	21,5	21,6
Te	0,6			0,8	0,6				1,5			
Pb	23,4	26,8	22,6	27,7	35,6	22,6	13,7	29,4	13,4		3,3	4,3
S												
Total	99,5	99,1	99,7	99,6	99,7	99,1	99,3	99,0	98,3	100,0	100,0	99,9
Proportions												
Pd	3,16	3,06	3,05	3,11	2,92	3,20	3,09	3,07	2,91	2,54	2,92	2,85
Cu	0,13	0,13	0,25	0,17	0,12	0,08	0,28	0,13	0,35	0,67	0,17	0,2
Fe	0,04	0,09	0,05	0,04	0,06	0,11	0,07		0,08	0,04	0,05	0,07
Sn	0,13	1,1	0,14			0,09	0,26	0,09	0,31	0,75	0,78	0,79
Te	0,03			0,04	0,03				0,06			
Pb	0,51	0,63	0,51	0,65	0,87	0,52	0,30	0,71	0,29		0,07	0,09
S												
Total	4,00	4,00	4,00	4,00	4,00	4,00	4,00	4,00	4,00	4,00	4,00	4,00

Abbreviations:
Silicates, FeTi-oxides, a.o.: ilm: ilmenite;
Sulphides: pn: pentlandite; bn: bornite: ch: chalcocine;
PGMs: Sk:Skaergaardite; zv: zvyagintsevite; at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy; Pd_2Te: unnamed phase;

Table 8 continued

Mineral	keithconite	vasilite		alloy	Unnamed Pd_2Te	
Grain	63 gr6	40 gr47	80 gr8	40 gr64	40 gr24	40 gr63
Association	sk+kth +bn	vs+ch	vs+bn	sk+bn+ (Pd,Cu,Sn)	Au_3Cu+ Pd_2Te	AuCu+ Pd_2Te
Analysis	13	17	18	14	15	16
wt%						
Pd	72,5	69,8	69,9	70,0	67,1	67,9
Cu	3,4	16,1	16,3	11,4		0,5
Fe		0,4	0,7		0,4	0,4
Sn	3,3			17,0		
Te	14,2			0.9	31,8	30,9
Pb	6,8					
S		12,7	12,9			
Total	99,4	99,0	99,8	99,3	99,3	99,7
Proportions						
Pd	2,95	11,49	11,38	0,67	1,97	1,98
Cu	0,17	4,44	4,44	0,18		0,02
Fe		0,13	9,22		0,02	0,02
Sn	0,12			0,14		
Te	0,62			0,01	1,00	0,97
Pb	0,14					
S		6,94	6,97			
Total	4,00	23,00	23,00	1,00	3,00	3,00

Abbreviations:

Silicates, FeTi-oxides, a.o.:	ilm: ilmenite;
Sulphides:	pn: pentlandite; bn: bornite: ch: chalcocine;
PGMs:	Sk:Skaergaardite; zv: zvyagintsevite; at: atokite; kth: keithconite; (Pd,Cu,Sn): alloy; Pd_2Te: unnamed phase;

PLATES

Plate 1

Relationships of rock-forming minerals, Fe-Ti oxides, sulphides and skaergaardite in the oxide-rich tholeitic gabbros of the sample 90-24, 1048 (1-8); polished section, SEM-image (BIE).

Abbreviations: pl: plagioclase; pl 1: liquidus plagioclase; pl II: plagioclase related to symplectites; pyr(exs): Ca-pyroxene with exsolutions of low Ca-pyroxene; cpx: clinopyroxene; opx: orthopyroxene; ol: olivine; ilm: ilmenite; timt: titanomagnetite; ap: apatite; bn: bornite; sk: skaergaardite.

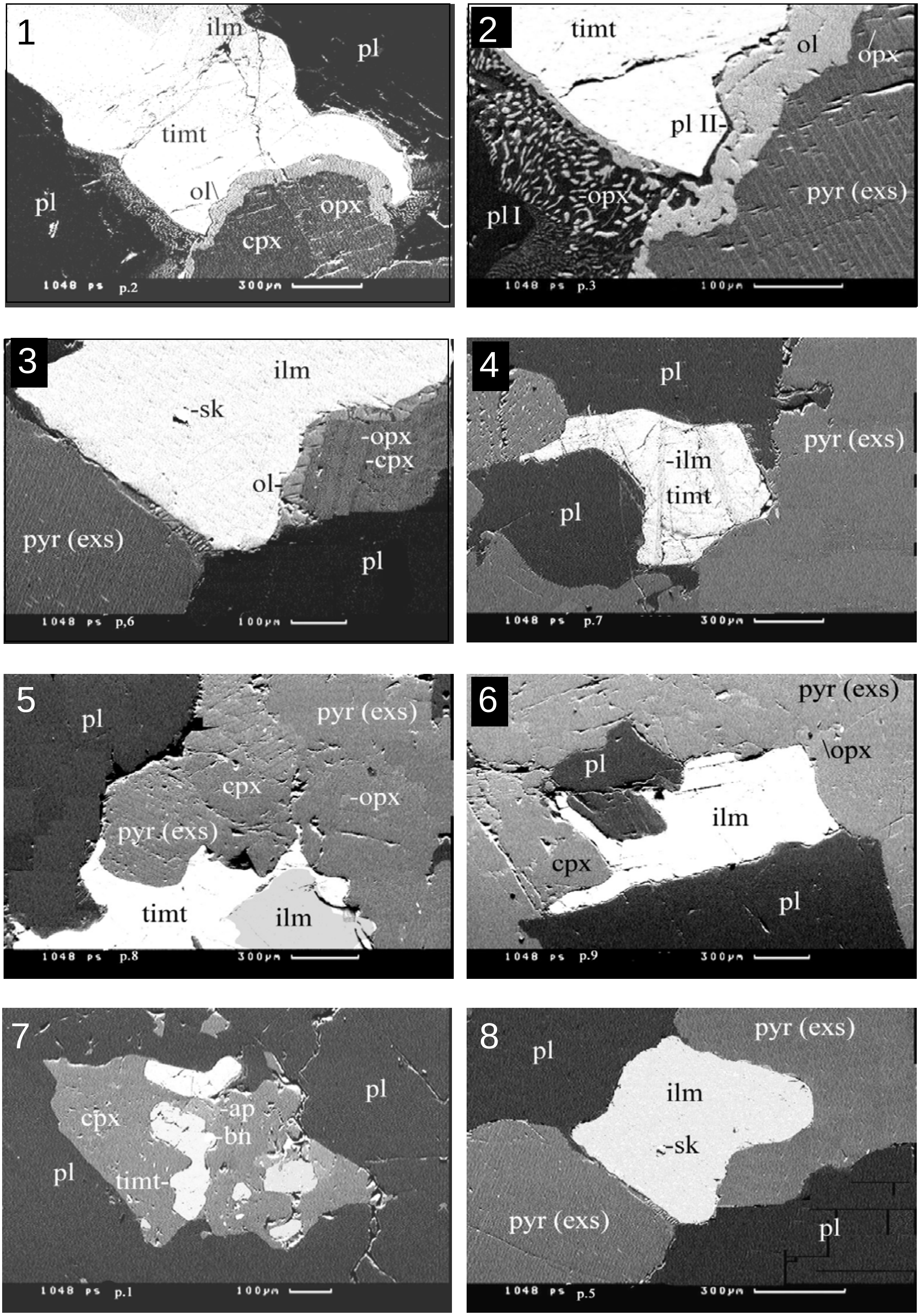
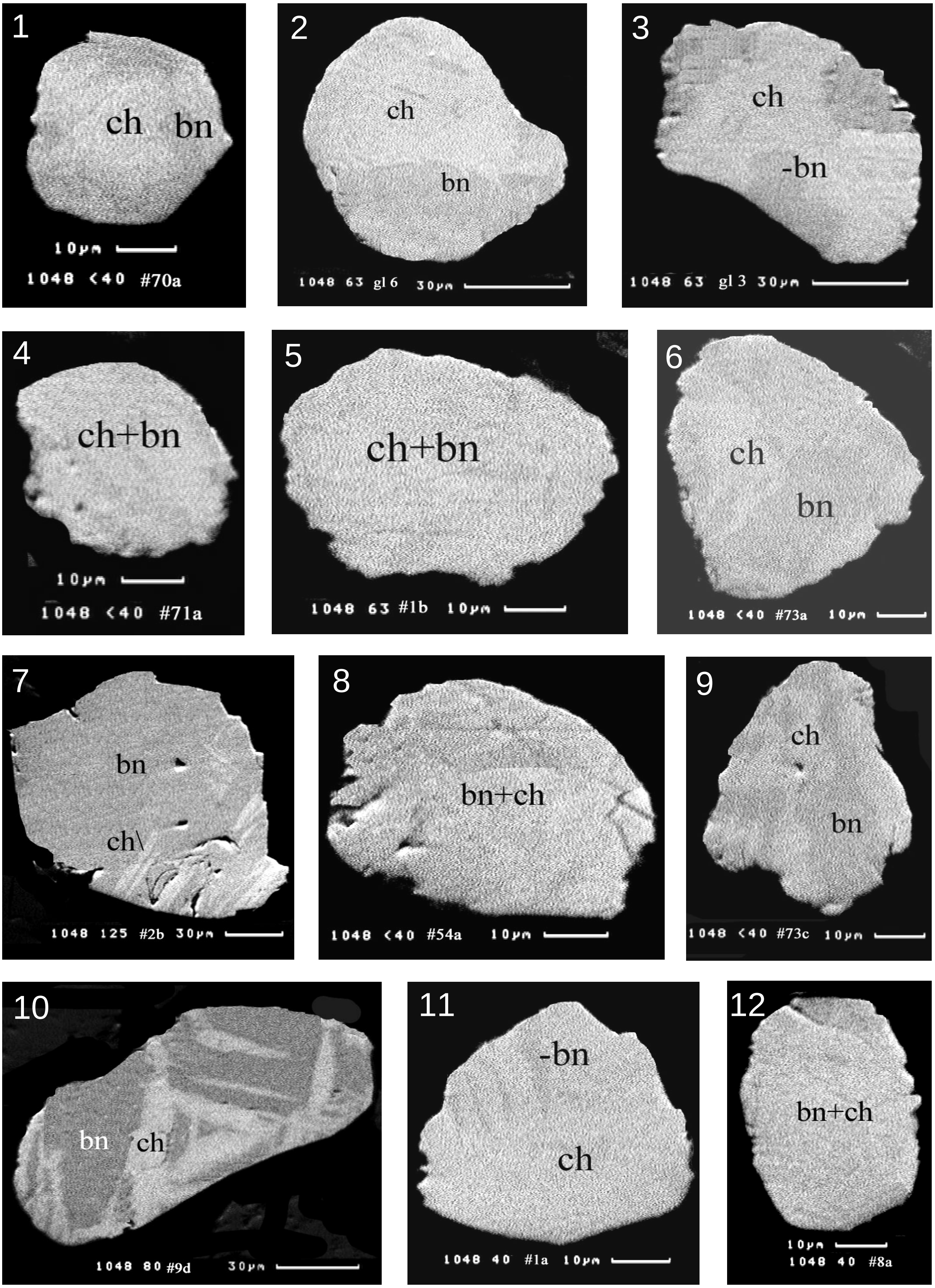

1
ilm
pl
timt
ol\
opx
pl
cpx
1048 ps p.2
300µm
2
timt
ol
opx
pl II-
pl I
-opx
pyr (exs)
1048 ps p.3
100µm
3
ilm
-sk
-opx
-cpx
ol-
pyr (exs)
pl
1048 ps p,6
100µm
4
pl
pyr (exs)
-ilm
timt
pl
1048 ps p.7
300µm
5
pl
pyr (exs)
cpx
-opx
pyr (exs)
timt
ilm
1048 ps p.8
300µm
6
pyr (exs)
\opx
pl
ilm
cpx
pl
1048 ps p.9
300µm
7
pl
cpx
-ap
-bn
pl
timt-
1048 ps p.1
100µm
8
pl
pyr (exs)
ilm
-sk
pyr (exs)
pl
1048 ps p.5
300µm

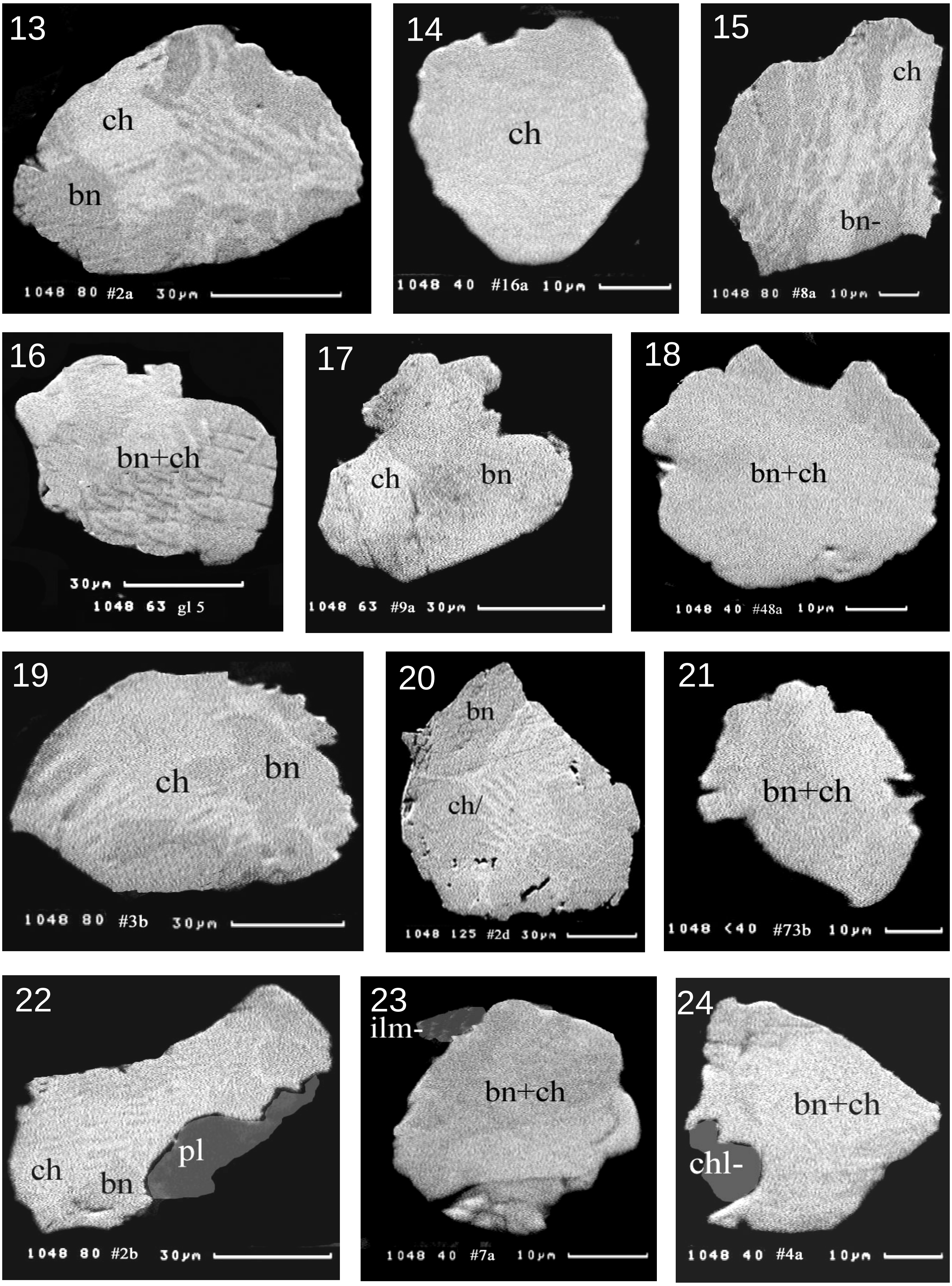
Plate 2

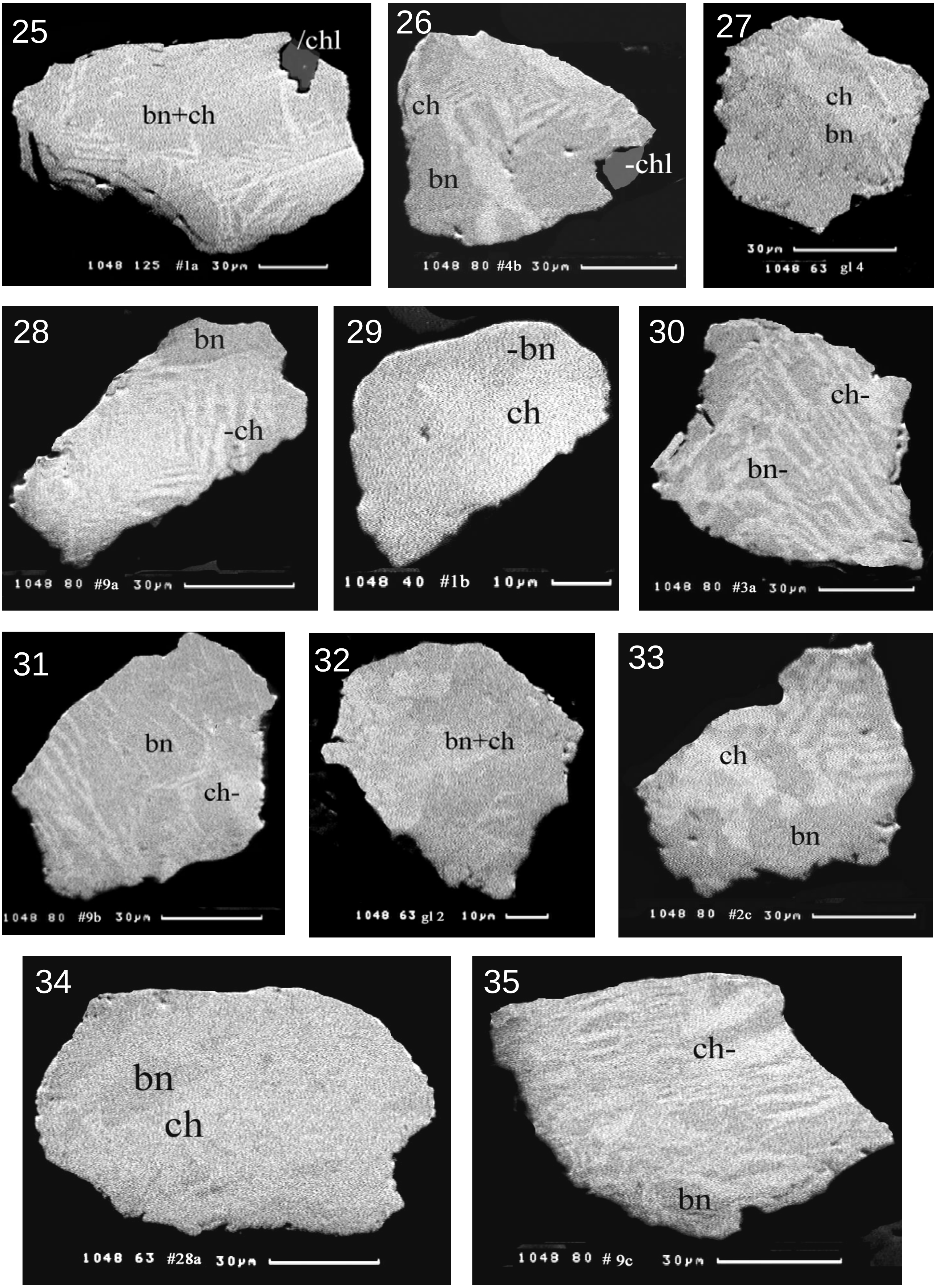
Sulphide mineralisation globules of oxide-rich tholeitic gabbros, sample 90-24 1048, image 1-39, polished section of grains, extracted in the heavy concentrate, SEM-image (BIE).

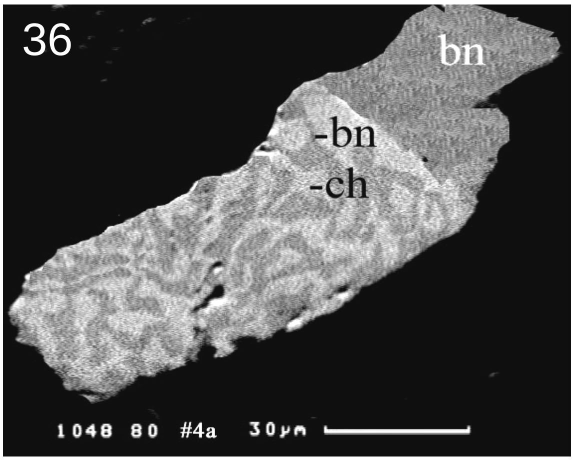
Abbreviations: ch: chalcocine; bn:bornite; pl: plagioclase; ilm: ilmenite; chl: chlorite;

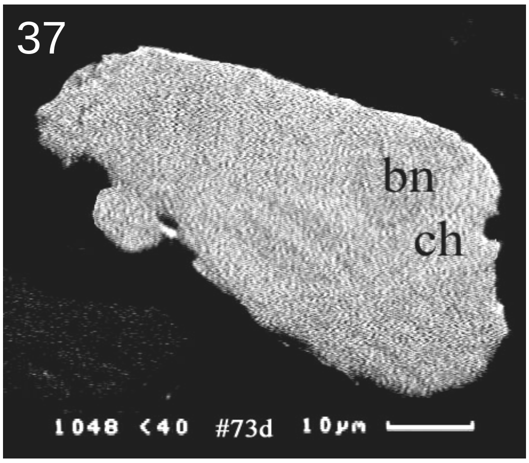


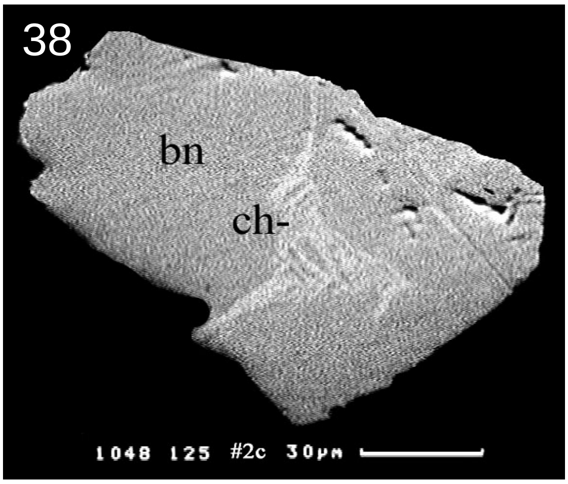
1
ch
bn
10μm
1048 <40 #70a
2
ch
bn
1048 63 gl 6 30μm
3
ch
-bn
1048 63 gl 3 30μm
4
ch+bn
10μm
1048 <40 #71a
5
ch+bn
1048 63 #1b 10μm
6
ch
bn
1048 <40 #73a 10μm
7
bn
ch\
1048 125 #2b 30μm
8
bn+ch
1048 <40 #54a 10μm
9
ch
bn
1048 <40 #73c 10μm
10
bn
ch
1048 80 #9d 30μm
11
-bn
ch
1048 40 #1a 10μm
12
bn+ch
10μm
1048 40 #8a


13
ch
bn
1048 80 #2a 30μm
14
ch
1048 40 #16a 10μm
15
ch
bn-
1048 80 #8a 10μm
16
bn+ch
30μm
1048 63 gl 5
17
ch
bn
1048 63 #9a 30μm
18
bn+ch
1048 40 #48a 10μm
19
ch
bn
1048 80 #3b 30μm
20
bn
ch/
1048 125 #2d 30μm
21
bn+ch
1048 <40 #73b 10μm
22
ch
bn
pl
1048 80 #2b 30μm
23
ilm-
bn+ch
1048 40 #7a 10μm
24
bn+ch
chl-
1048 40 #4a 10μm


25
/chl
bn+ch
1048 125 #1a 30μm
26
ch
bn
-chl
1048 80 #4b 30μm
27
ch
bn
30μm
1048 63 gl 4
28
bn
-ch
1048 80 #9a 30μm
29
-bn
ch
1048 40 #1b 10μm
30
ch-
bn-
1048 80 #3a 30μm
31
bn
ch-
1048 80 #9b 30μm
32
bn+ch
1048 63 gl 2 10μm
33
ch
bn
1048 80 #2c 30μm
34
bn
ch
1048 63 #28a 30μm
35
ch-
bn
1048 80 # 9c 30μm


36
bn
-bn
-ch
1048 80 #4a 30µm


37
bn
ch
1048 <40 #73d 10µm


38
bn
ch-
1048 125 #2c 30µm

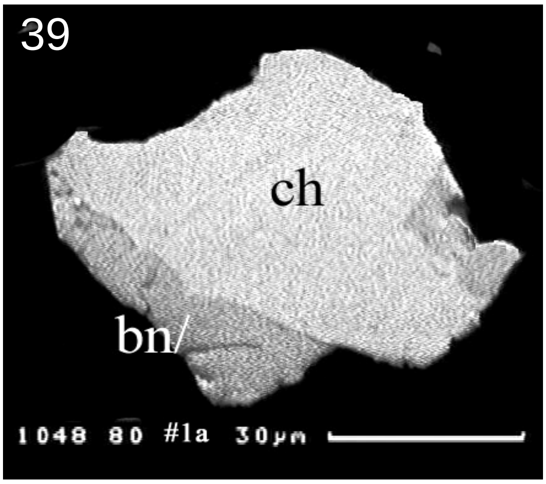
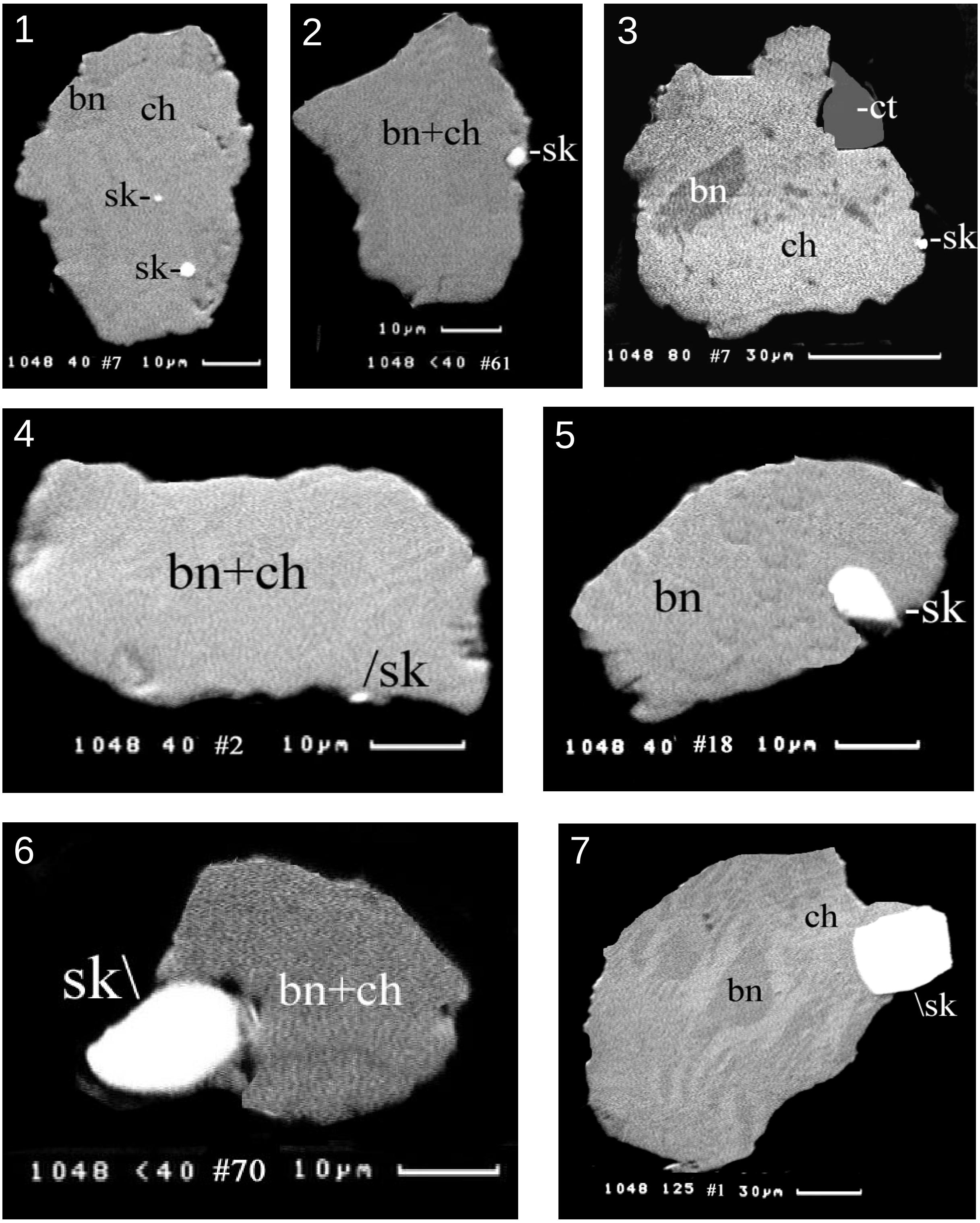
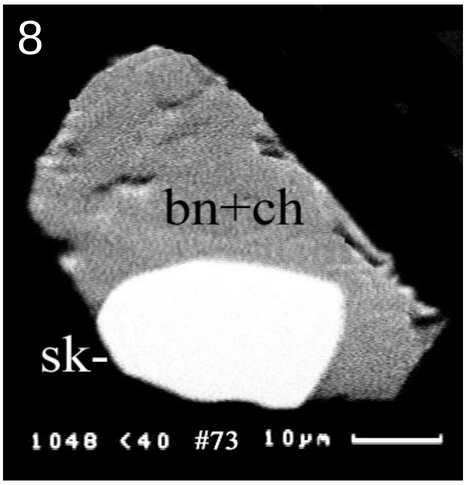

39
ch
bn/
1048 80 #1a 30µm

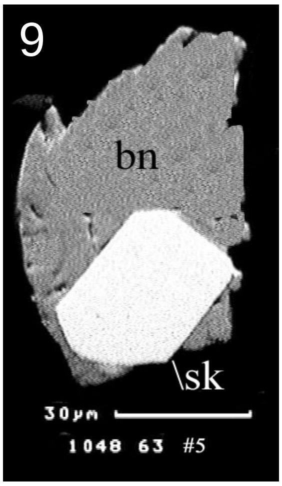
Plate 3

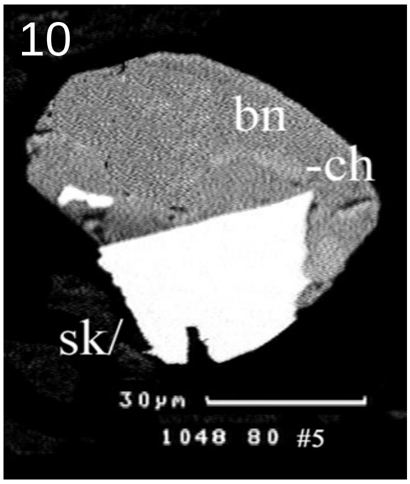
Sulphide globules with inclusions of skaergaardite (**bms**) and skaergaardite particles attached base metal sulphides (**bms-L**)- in the heavy mineral concentrates of sample 90-24 1048; images 1-49; polished section, SEM-image (BIE).

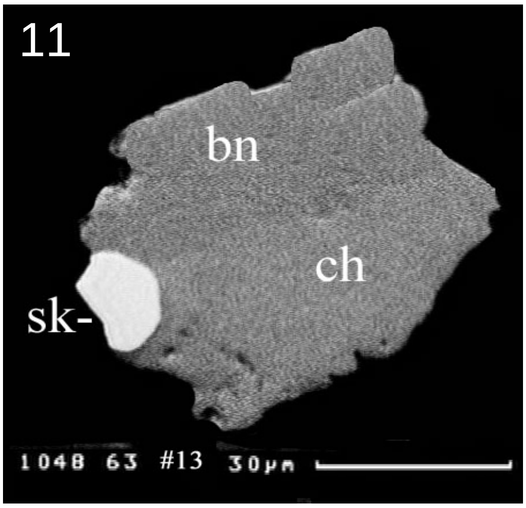
Abbreviations: bn: bornite; ch: chalcocine; cp: chalcopyrite; pn: pentlandite; pn(Co) coboltian pentlandite; sk: skaergaardite; Cu_2FeS_3: unnamed Cu-sulphide; ct: calcite.

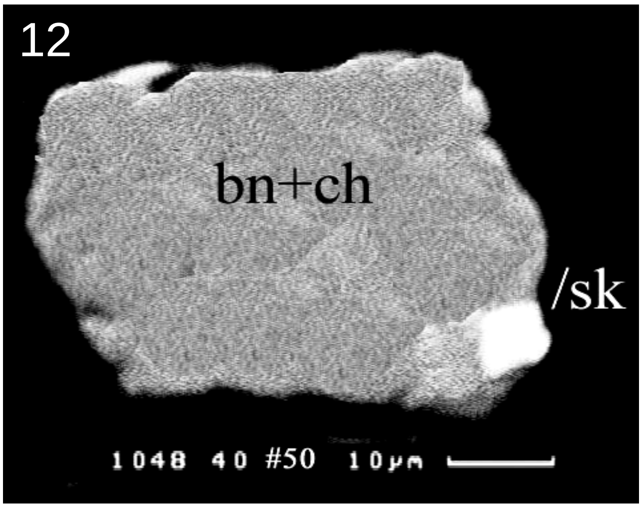

1
bn
ch
sk-
sk-
1048 40 #7 10μm
2
bn+ch
-sk
10μm
1048 <40 #61
3
-ct
bn
ch
-sk
1048 80 #7 30μm
4
bn+ch
/sk
1048 40 #2 10μm
5
bn
-sk
1048 40 #18 10μm
6
sk\
bn+ch
1048 <40 #70 10μm
7
ch
bn
\sk
1048 125 #1 30μm

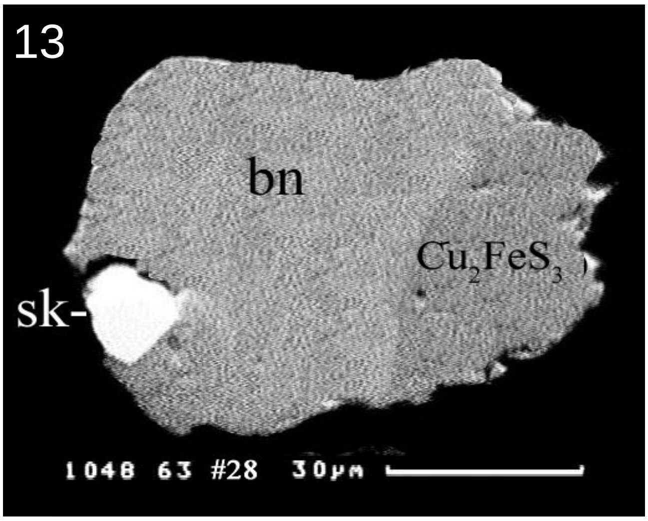

8
bn+ch
sk-
1048 <40 #73 10µm

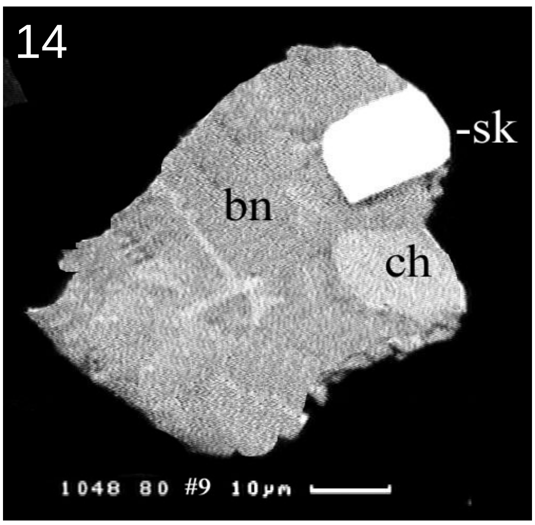

9
bn
\sk
30µm
1048 63 #5

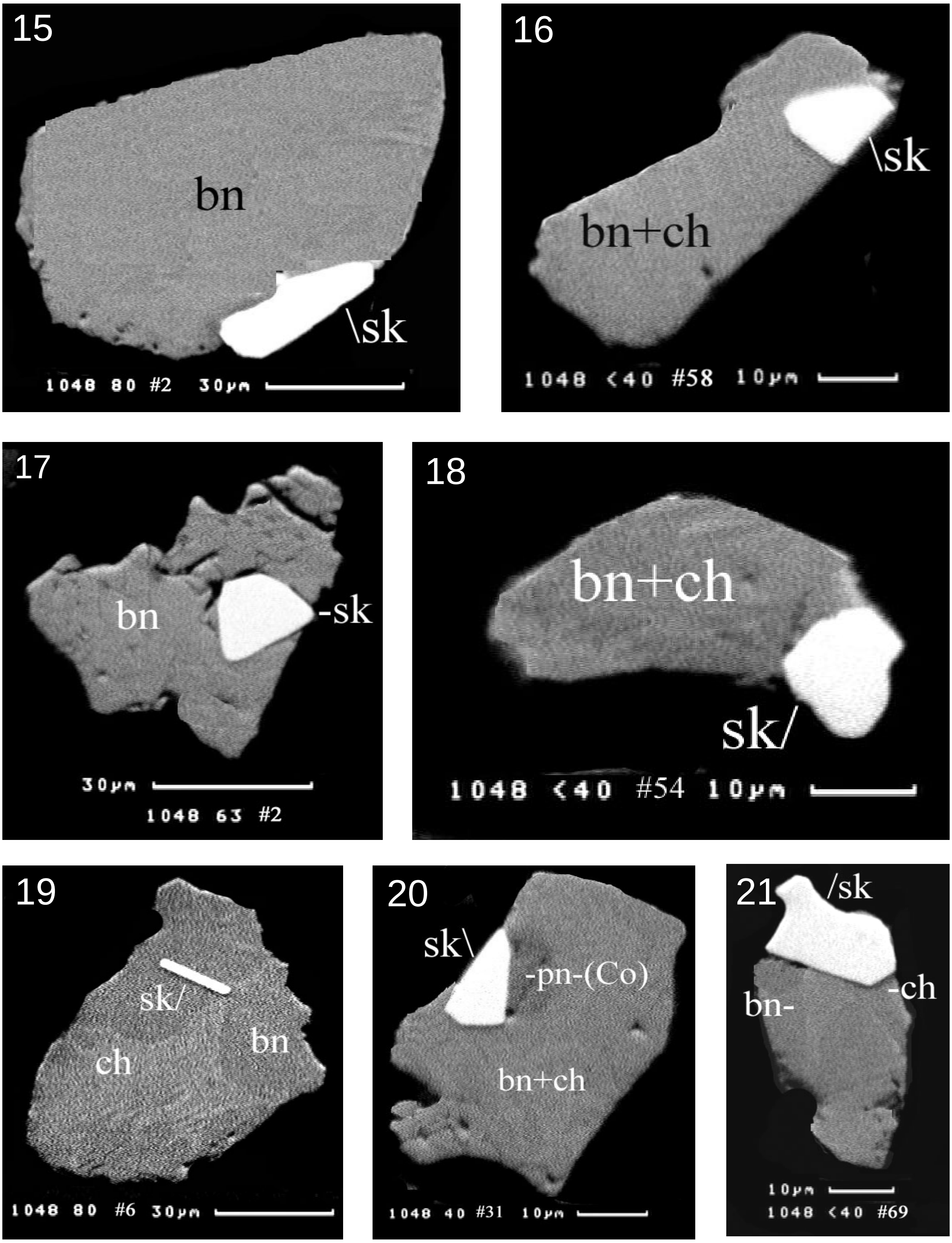

10
bn
-ch
sk/
30µm
1048 80 #5

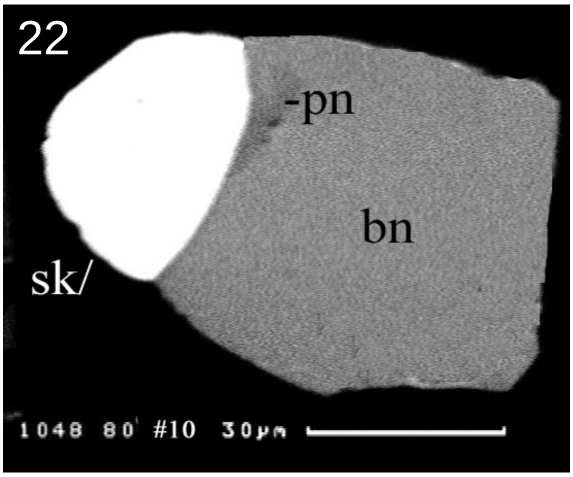

11
bn
ch
sk-
1048 63 #13 30µm

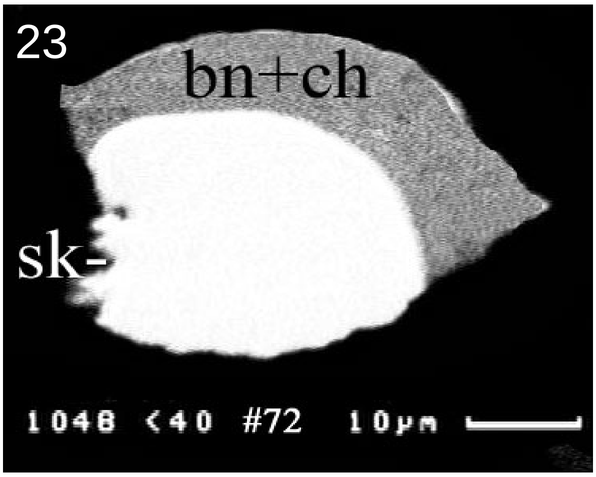

12
bn+ch
/sk
1048 40 #50 10µm

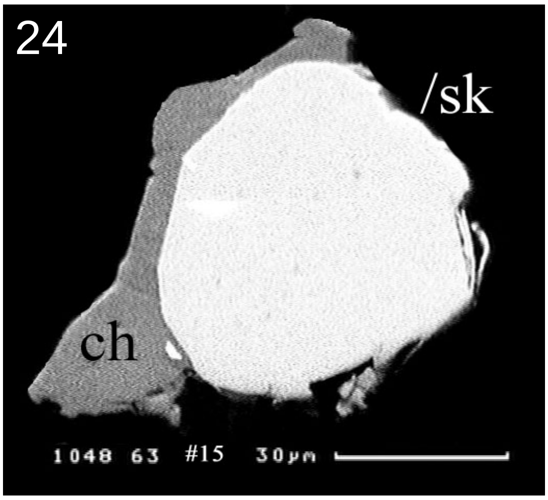

13
bn
Cu2FeS3
sk-
1048 63 #28 30µm

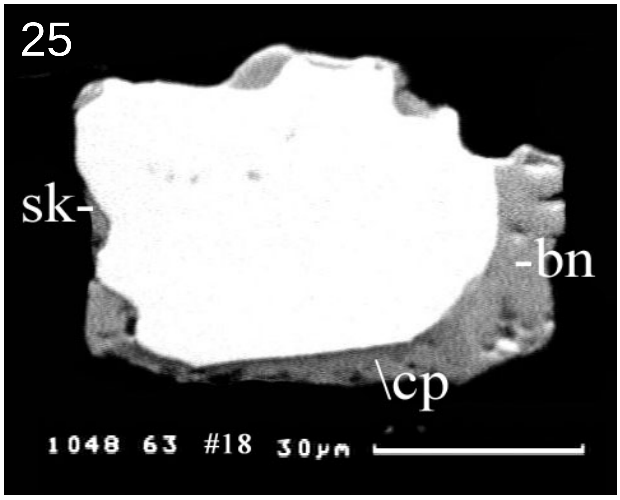

14
-sk
bn
ch
1048 80 #9 10µm

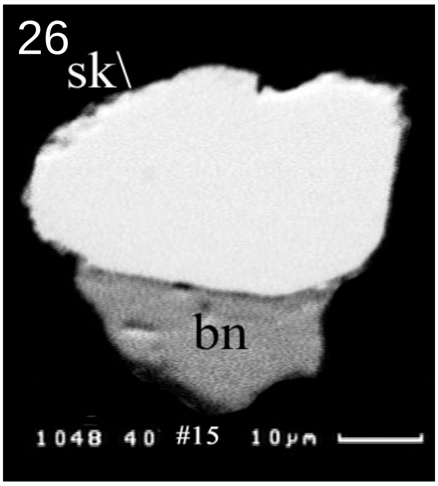

15
bn
\sk
1048 80 #2 30µm
16
\sk
bn+ch
1048 <40 #58 10µm
17
bn
-sk
30µm
1048 63 #2
18
bn+ch
sk/
1048 <40 #54 10µm
19
sk/
bn
ch
1048 80 #6 30µm
20
sk\
-pn-(Co)
bn+ch
1048 40 #31 10µm
21
/sk
-ch
bn-
10µm
1048 <40 #69

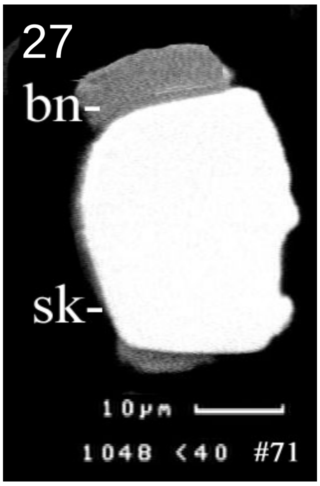

22
-pn
bn
sk/
1048 80 #10 30μm

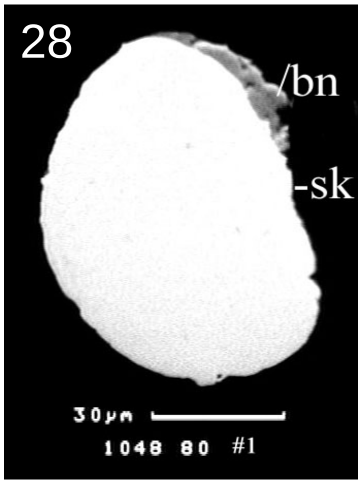

23
bn+ch
sk-
1048 <40 #72 10μm

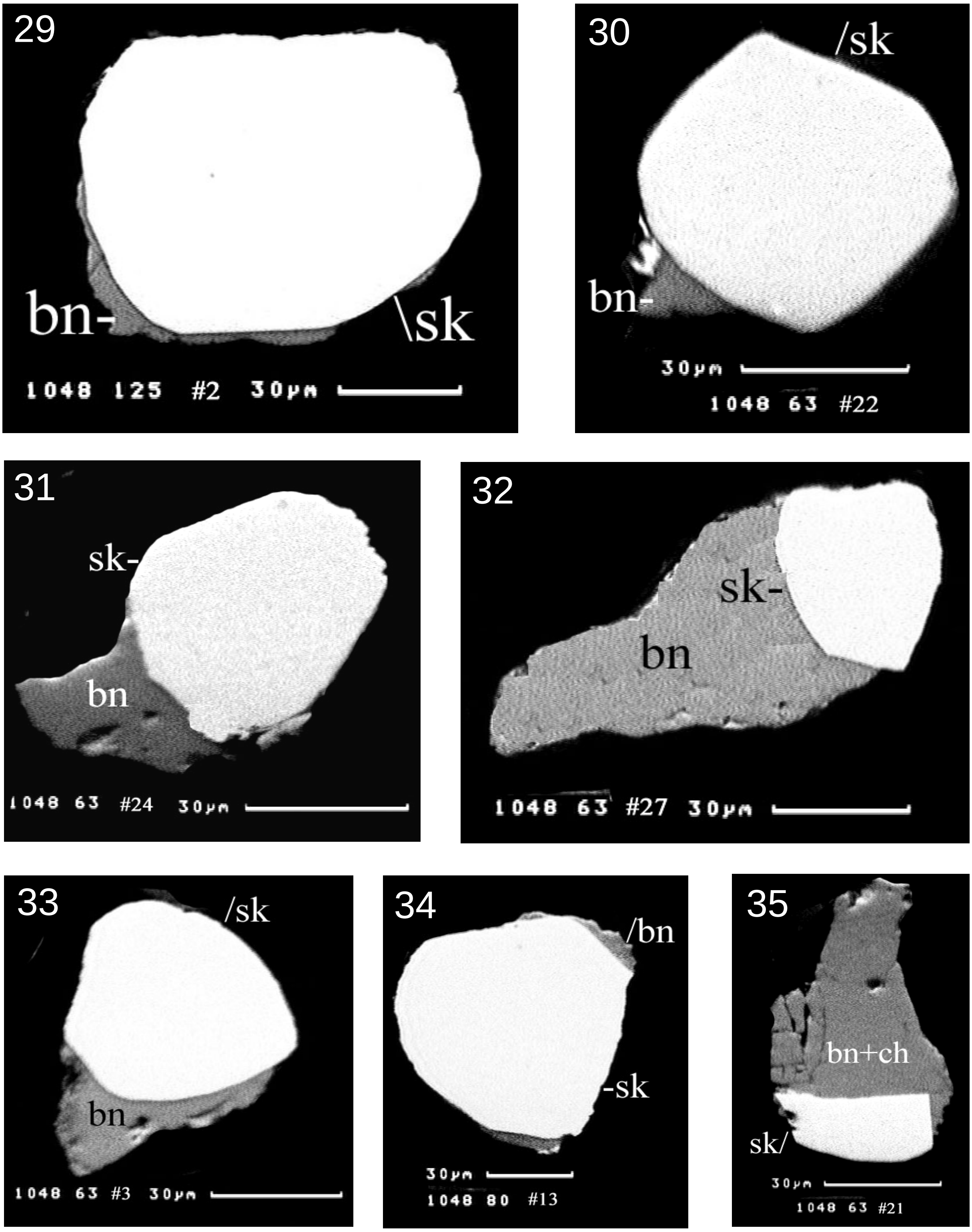

24
/sk
ch
1048 63 #15 30μm

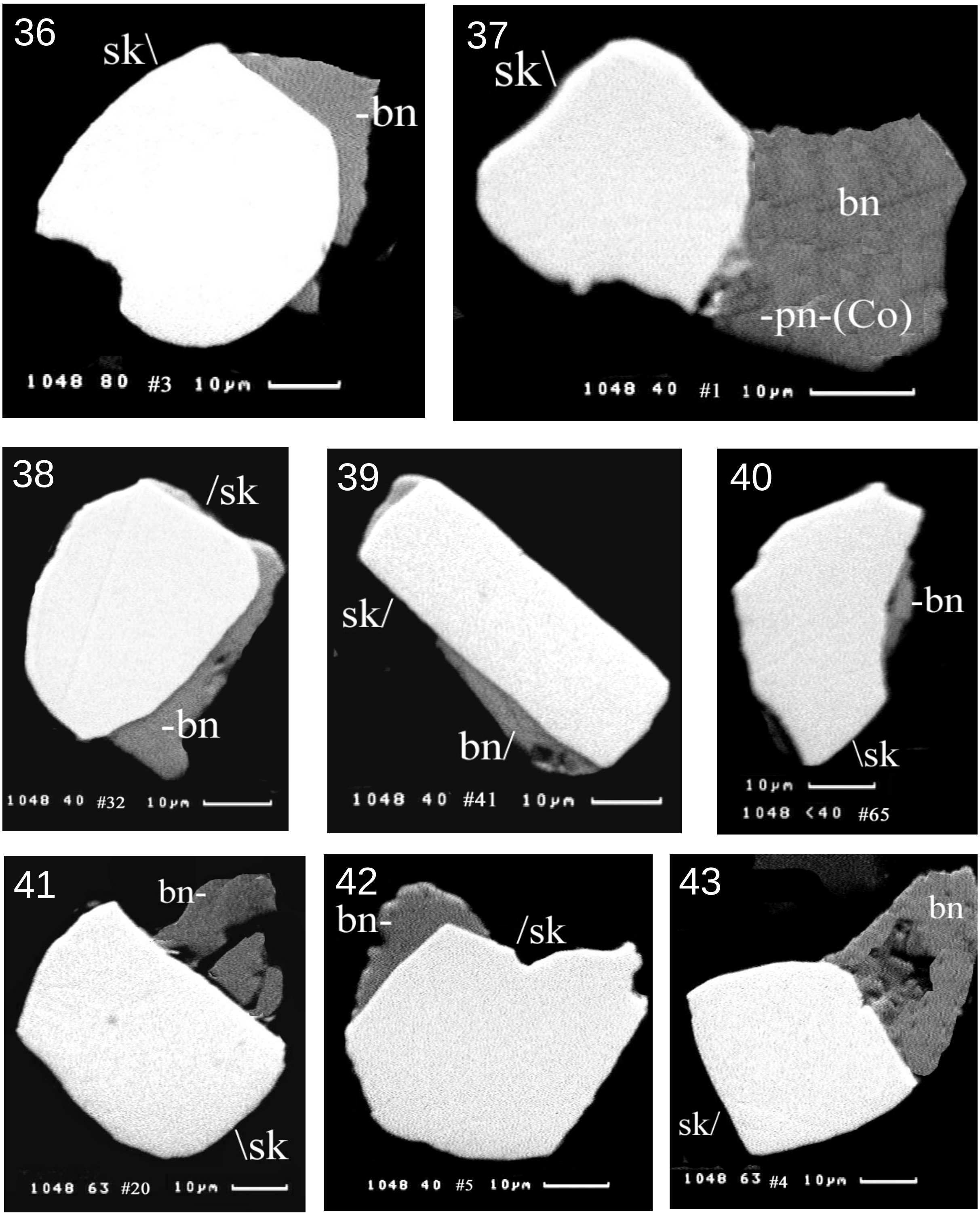

25
sk-
-bn
\cp
1048 63 #18 30μm

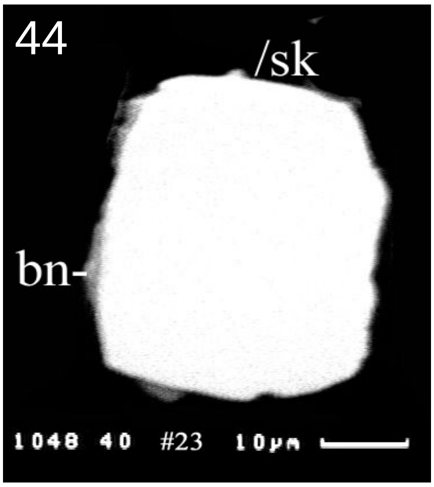

26
sk\
bn
1048 40 #15 10μm

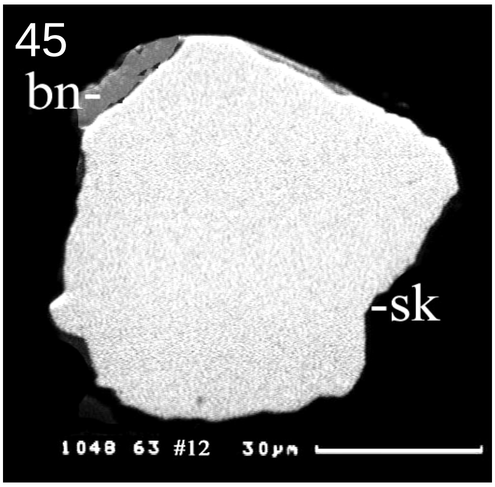

27
bn-
sk-
10μm
1048 <40 #71

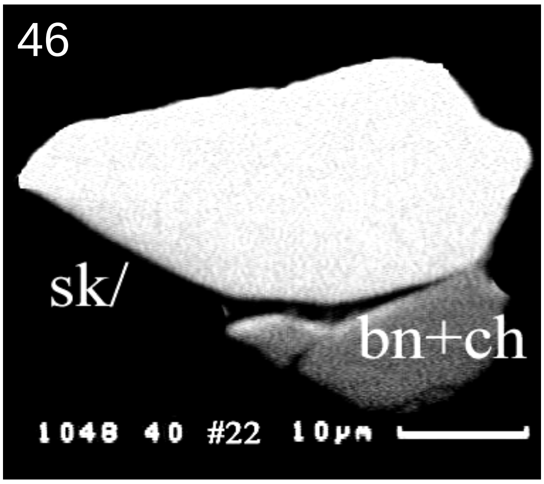

28
/bn
-sk
30μm
1048 80 #1

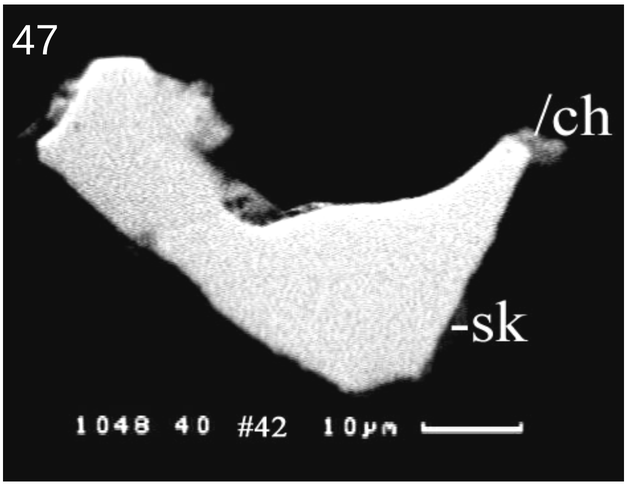

29
bn-
\sk
1048 125 #2 30μm
30
/sk
bn-
30μm
1048 63 #22
31
sk-
bn
1048 63 #24 30μm
32
sk-
bn
1048 63 #27 30μm
33
/sk
bn
1048 63 #3 30μm
34
/bn
-sk
30μm
1048 80 #13
35
bn+ch
sk/
30μm
1048 63 #21

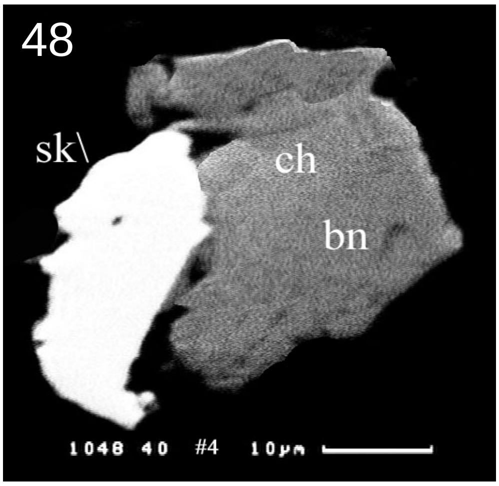

36
sk\
-bn
1048 80 #3 10μm
37
sk\
bn
-pn-(Co)
1048 40 #1 10μm
38
/sk
-bn
1048 40 #32 10μm
39
sk/
bn/
1048 40 #41 10μm
40
-bn
\sk
10μm
1048 <40 #65
41
bn-
\sk
1048 63 #20 10μm
42
bn-
/sk
1048 40 #5 10μm
43
bn
sk/
1048 63 #4 10μm


44
/sk
bn-
1048 40 #23 10μm


45
bn-
-sk
1048 63 #12 30μm


46
sk/
bn+ch
1048 40 #22 10μm


47
/ch
-sk
1048 40 #42 10μm


48
sk\
ch
bn
1048 40 #4 10μm

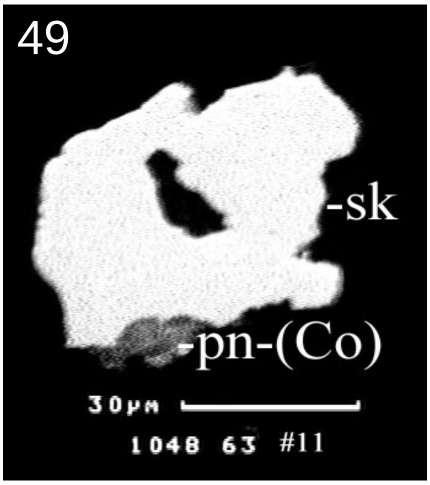
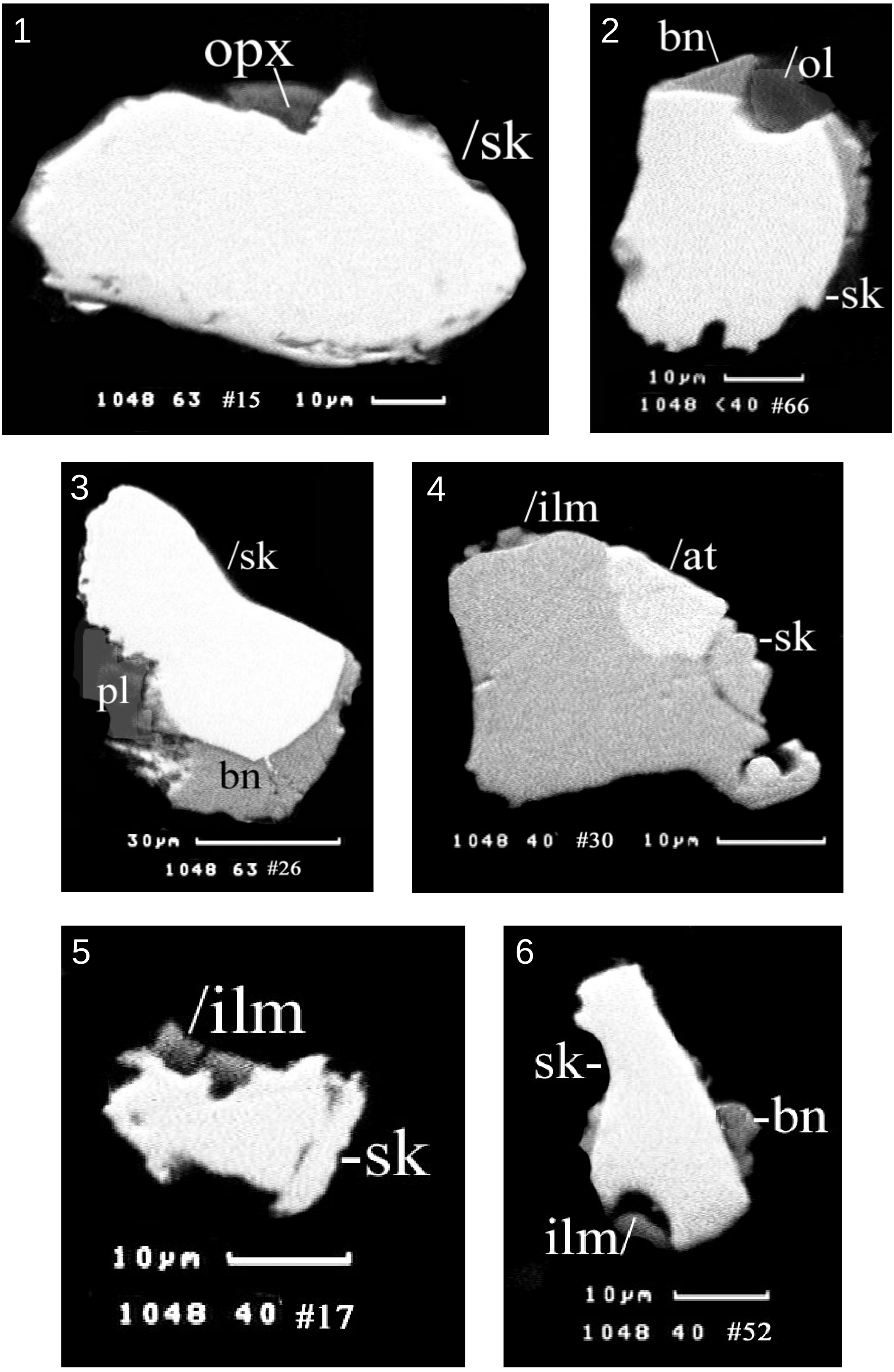

49
-sk
-pn-(Co)
30μm
1048 63 #11

Plate 4

Skaergaardite grains attached to gangue or to gangue+sulphides in the heavy mineral concentrates of sample 90-24 1048, images1-10; polished section, SEM-image (BIE).

Abbreviations: Silicates: opx: orthopyroxene; ol: olivine; pl: plagioclase; chl: chlorite
Sulphides: bn: bornite; Cu_2FeS_3: unnamed Cu-sulphide
PGMs: sk: skaergaardite; at: atokite
Others: ilm: ilmenite; ThO_2; ct: calcite


1
opx
/sk
1048 63 #15 10μm
2
bn\
/ol
-sk
10μm
1048 <40 #66
3
/sk
pl
bn
30μm
1048 63 #26
4
/ilm
/at
-sk
1048 40 #30 10μm
5
/ilm
-sk
10μm
1048 40 #17
6
sk-
-bn
ilm/
10μm
1048 40 #52

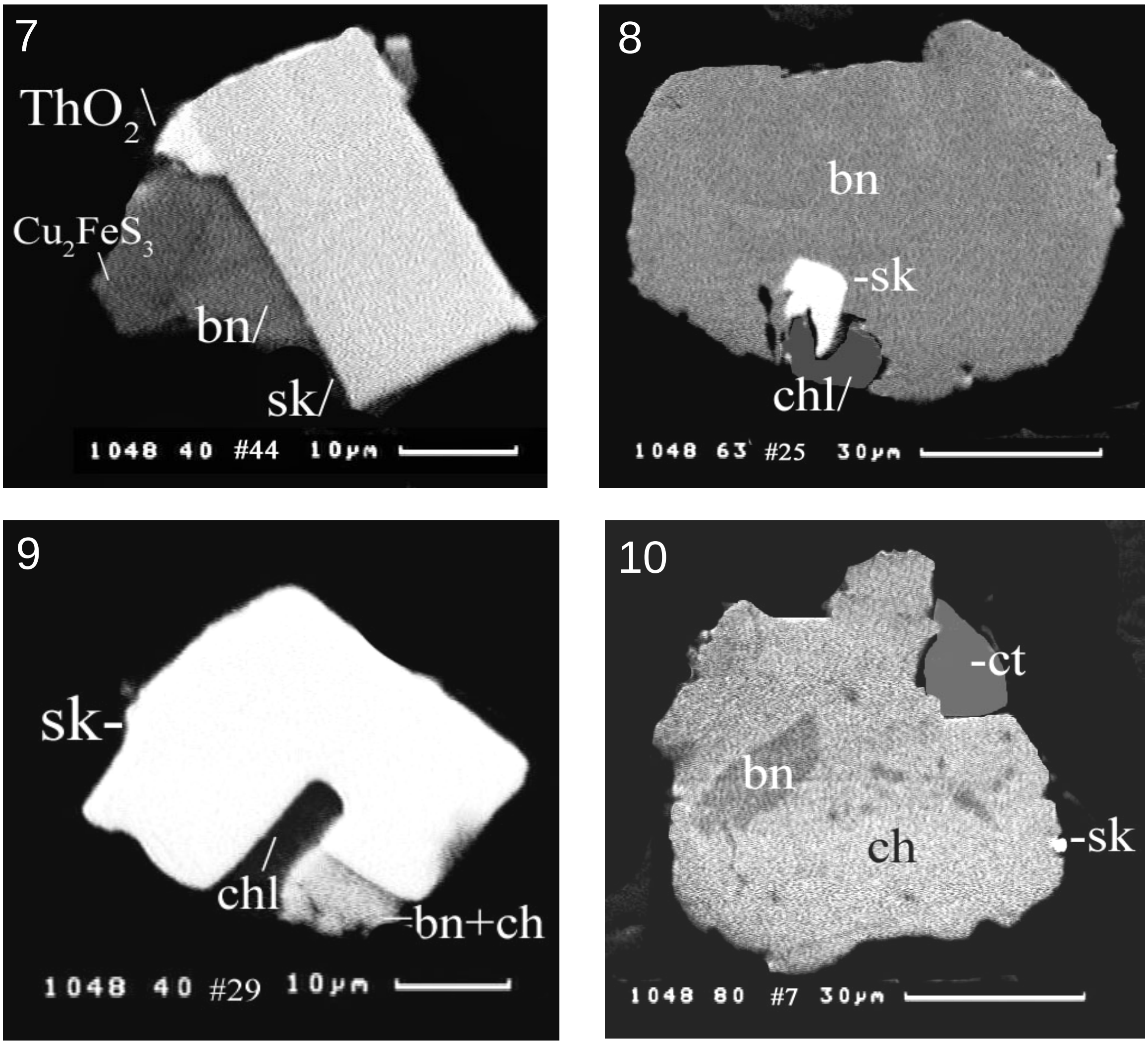
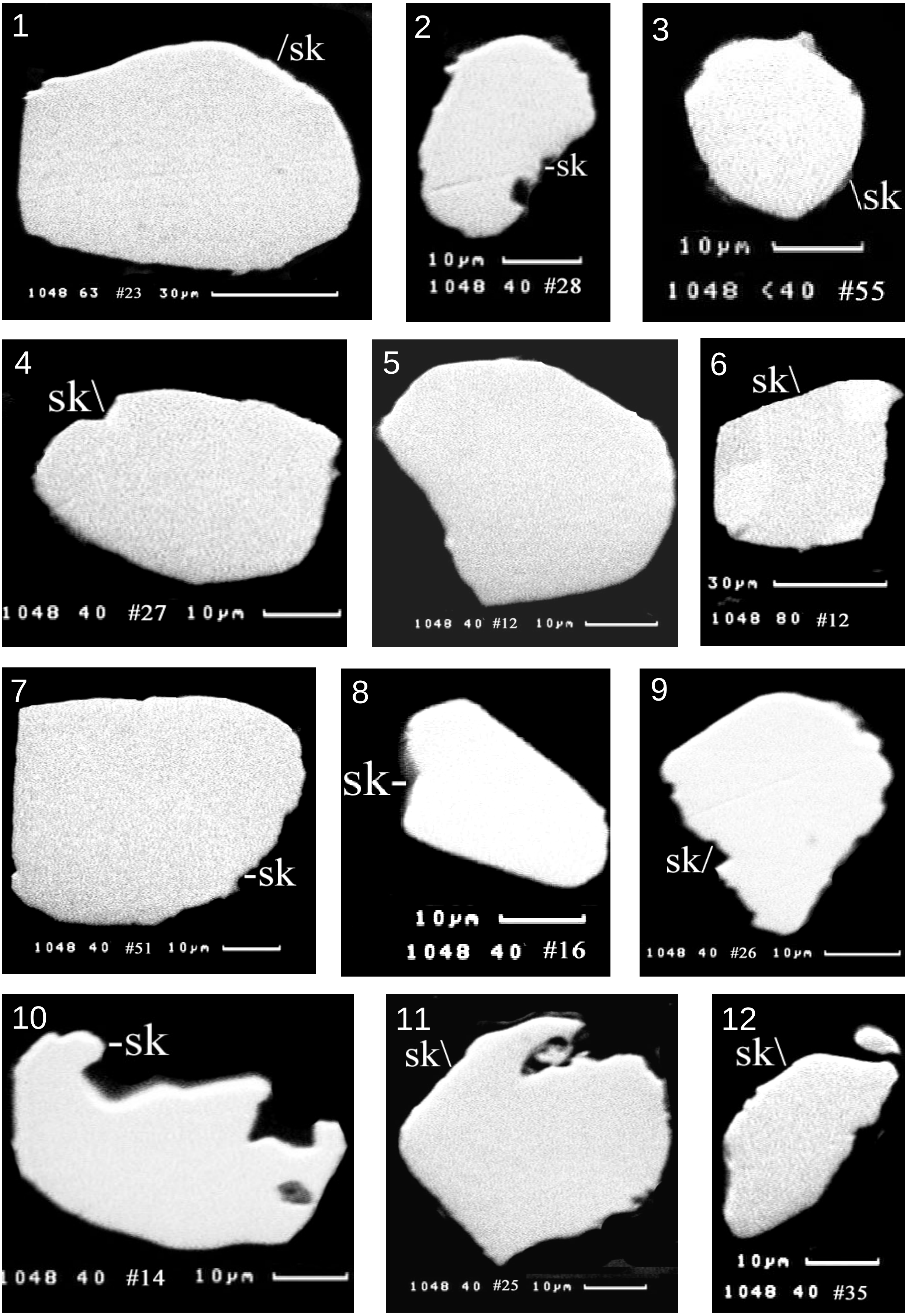

7
ThO2\
Cu2FeS3
bn/
sk/
1048 40 #44 10μm
8
bn
-sk
chl/
1048 63 #25 30μm
9
sk-
chl
bn+ch
1048 40 #29 10μm
10
-ct
bn
ch
-sk
1048 80 #7 30μm

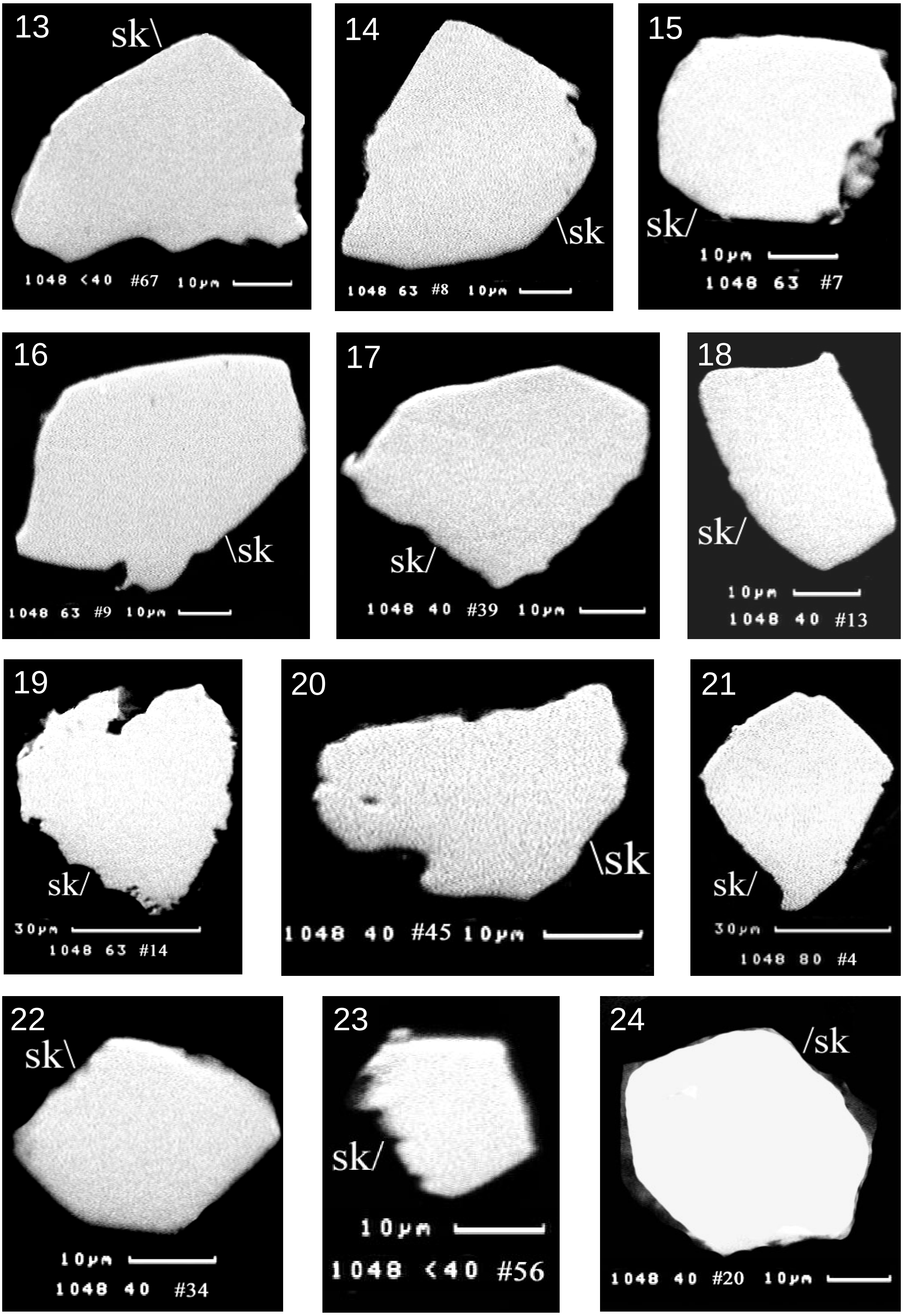
Plate 5

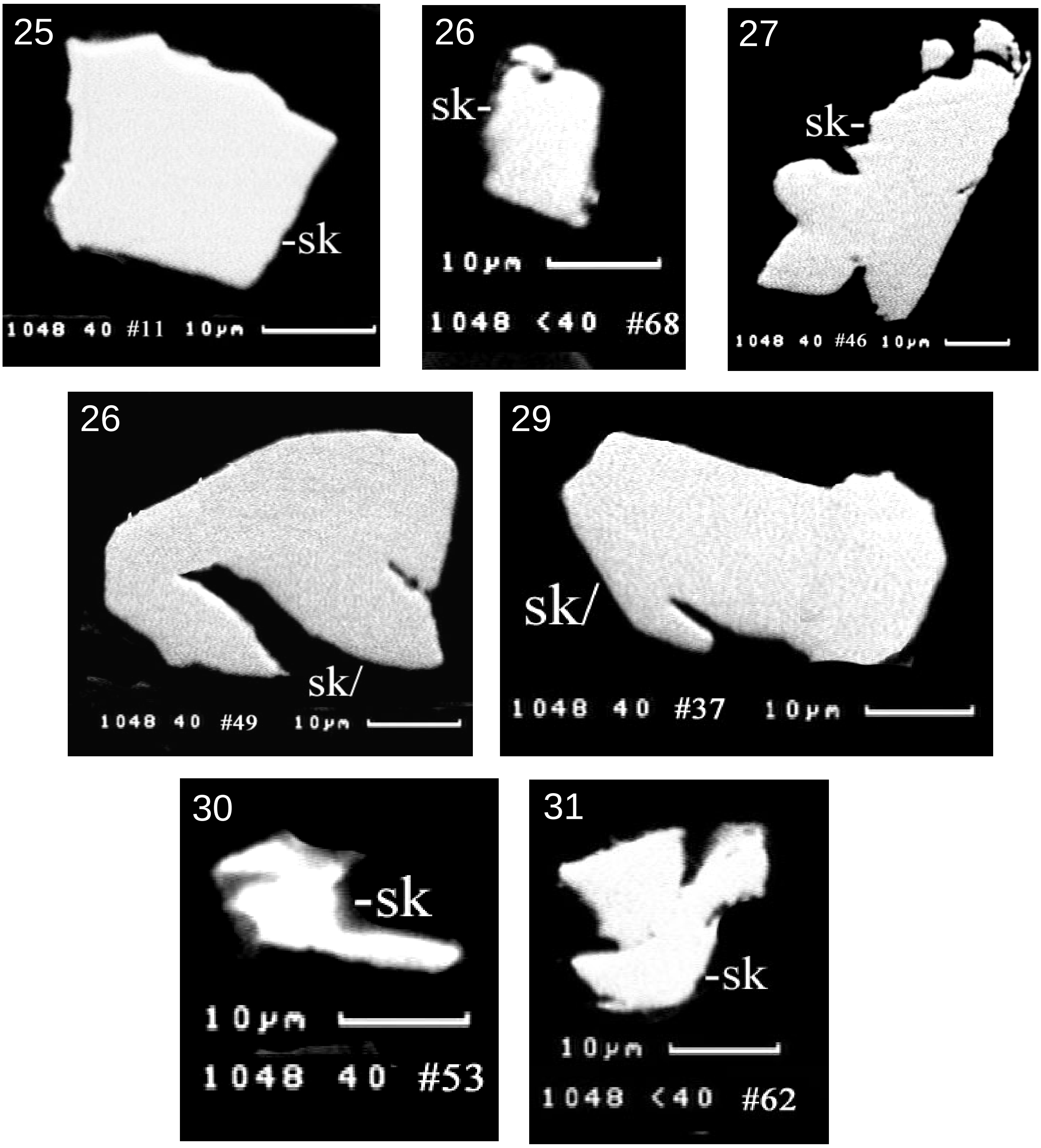
Completely liberated grains of skaergaardite (**L**) in the heavy mineral concentrates of sample 90-24 1048, images1-31; polished section, SEM-images (BIE).

Abbreviations: sk: skaergaardite



1
/sk
1048 63 #23 30μm
2
-sk
10μm
1048 40 #28
3
\sk
10μm
1048 <40 #55
4
sk\
1048 40 #27 10μm
5
1048 40 #12 10μm
6
sk\
30μm
1048 80 #12
7
-sk
1048 40 #51 10μm
8
sk-
10μm
1048 40 #16
9
sk/
1048 40 #26 10μm
10
-sk
1048 40 #14 10μm
11
sk\
1048 40 #25 10μm
12
sk\
10μm
1048 40 #35


13
sk\
1048 <40 #67 10μm
14
\sk
1048 63 #8 10μm
15
sk/
10μm
1048 63 #7
16
\sk
1048 63 #9 10μm
17
sk/
1048 40 #39 10μm
18
sk/
10μm
1048 40 #13
19
sk/
30μm
1048 63 #14
20
\sk
1048 40 #45 10μm
21
sk/
30μm
1048 80 #4
22
sk\
10μm
1048 40 #34
23
sk/
10μm
1048 <40 #56
24
/sk
1048 40 #20 10μm



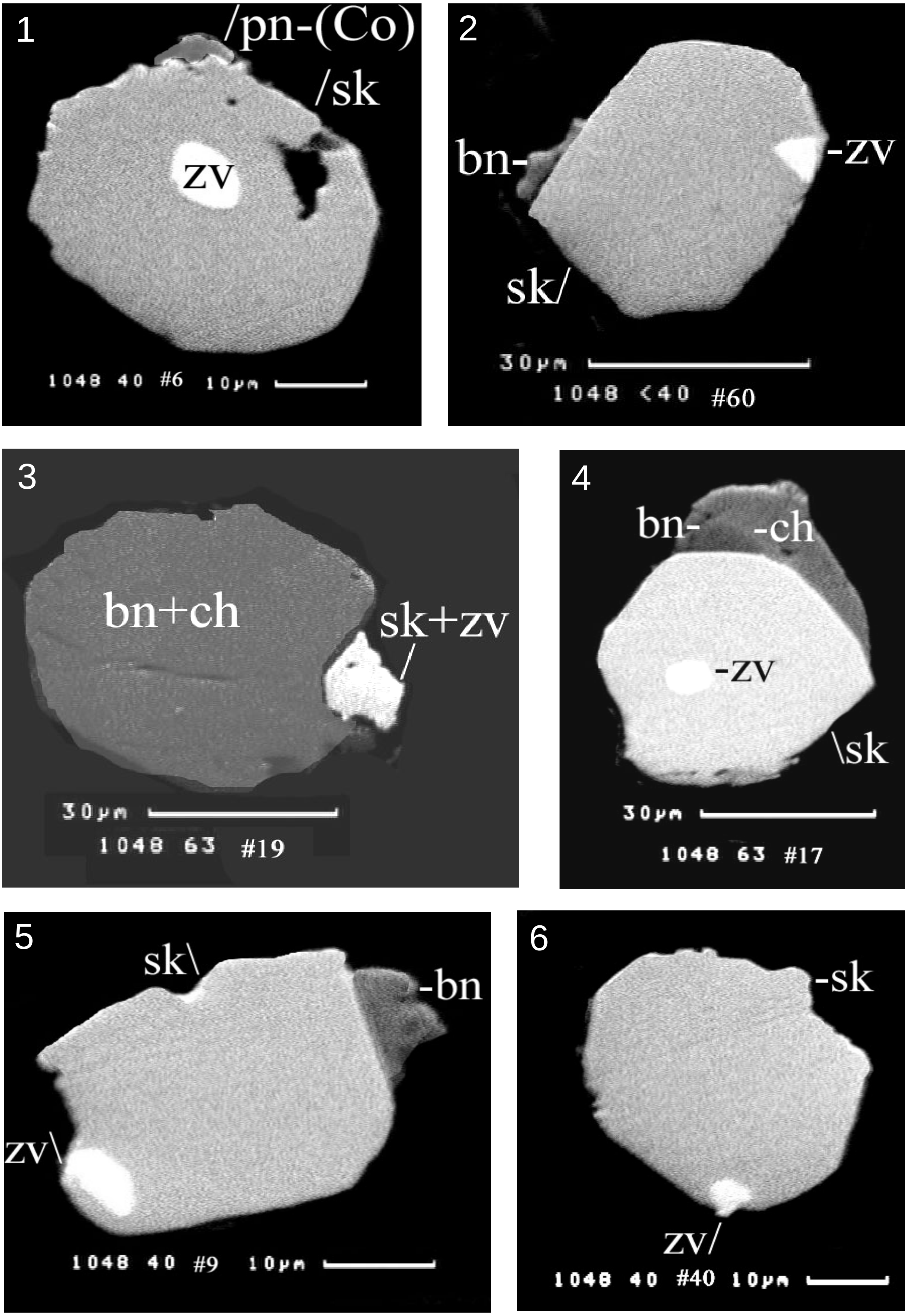
25
-sk
1048 40 #11 10μm
26
sk-
10μm
1048 <40 #68
27
sk-
1048 40 #46 10μm
26
sk/
1048 40 #49 10μm
29
sk/
1048 40 #37 10μm
30
-sk
10μm
1048 40 #53
31
-sk
10μm
1048 <40 #62

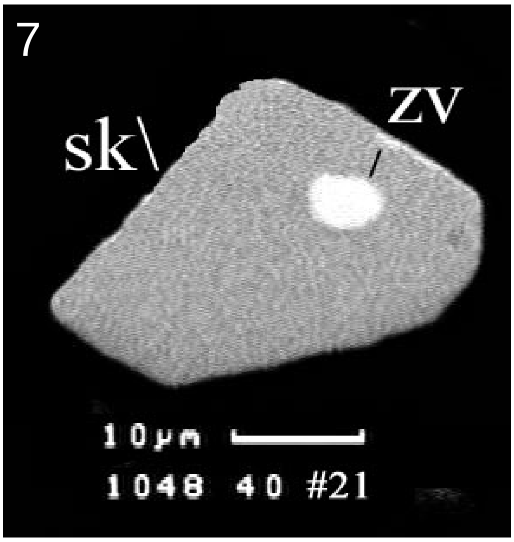
Plate 6

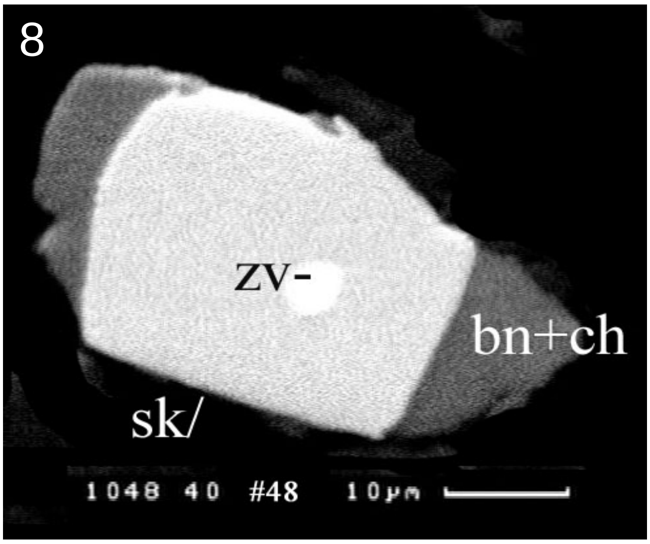
PGM grains containing zvyagintsevite (images 1-9), atokite (images 10-13), (Pd,Cu,Sn) alloy (image14), keithconite (images 15-16) and vasilite (images 17-19) in the heavy mineral concentrates of sample 90-24 1048; polished section, SEM-image (BIE).

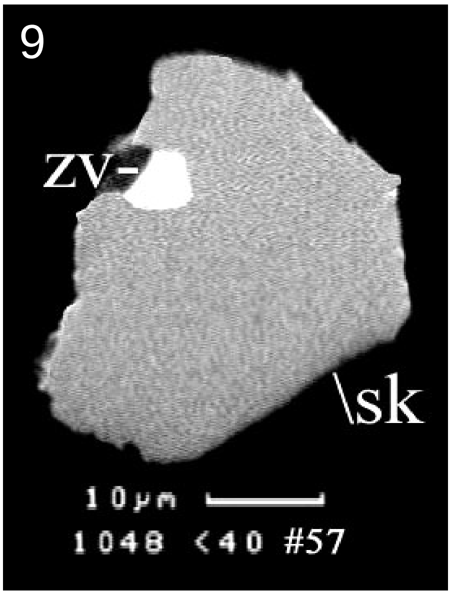
Abbreviations:

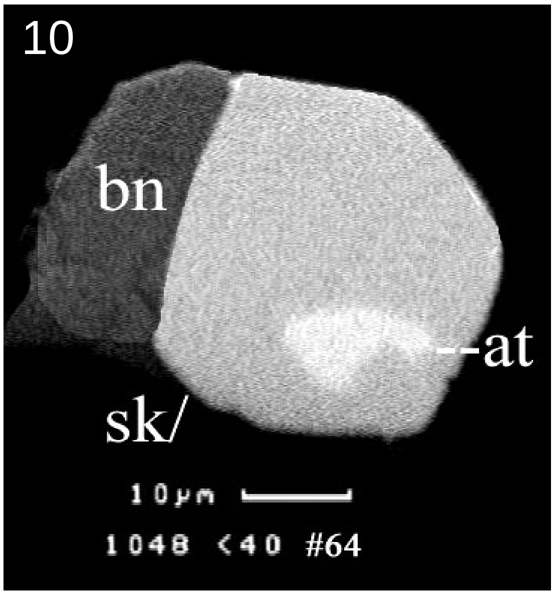
sulphides:	bn: bornite; pn-(Co): coboltian pentlandite; ch: chalcocine;
PGMs:	sk: skaergaardite; zv: zvyagintsevite; at: atokite; (Pd,Cu,Sn): unnamed alloy; kth: keithconite; vs: vasilite
Others:	ilm: ilmenite;

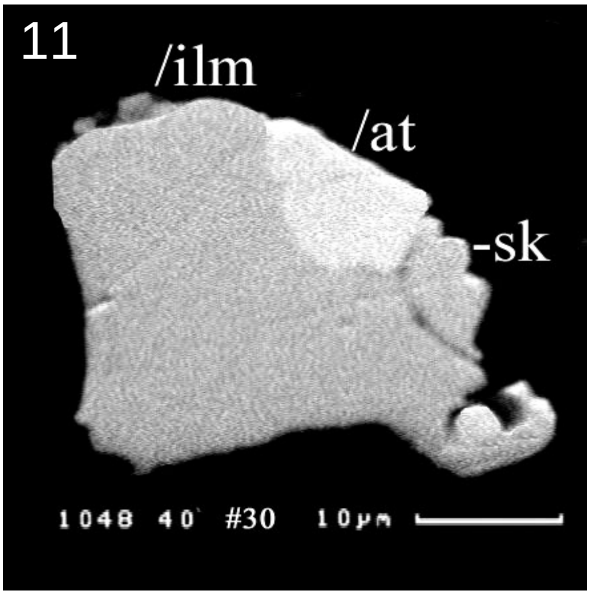

1
/pn-(Co)
/sk
zv
1048 40 #6 10µm
2
bn-
-zv
sk/
30µm
1048 <40 #60
3
bn+ch
sk+zv
30µm
1048 63 #19
4
bn-
-ch
-zv
\sk
30µm
1048 63 #17
5
sk\
-bn
zv\
1048 40 #9 10µm
6
-sk
zv/
1048 40 #40 10µm

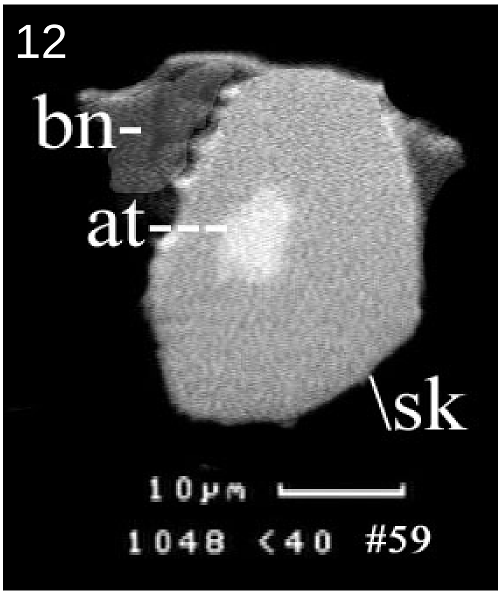

7
sk\
ZV
10µm
1048 40 #21

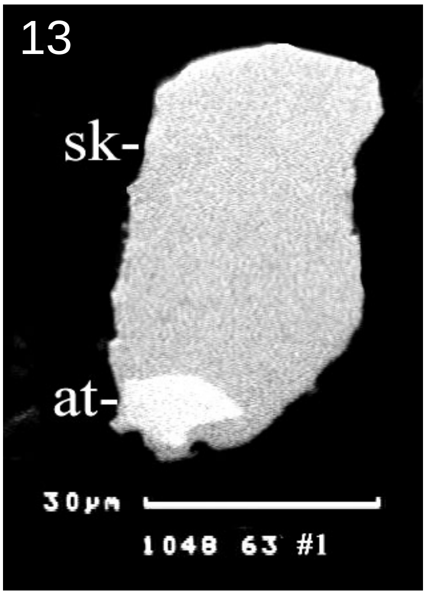

8
zv-
bn+ch
sk/
1048 40 #48
10µm

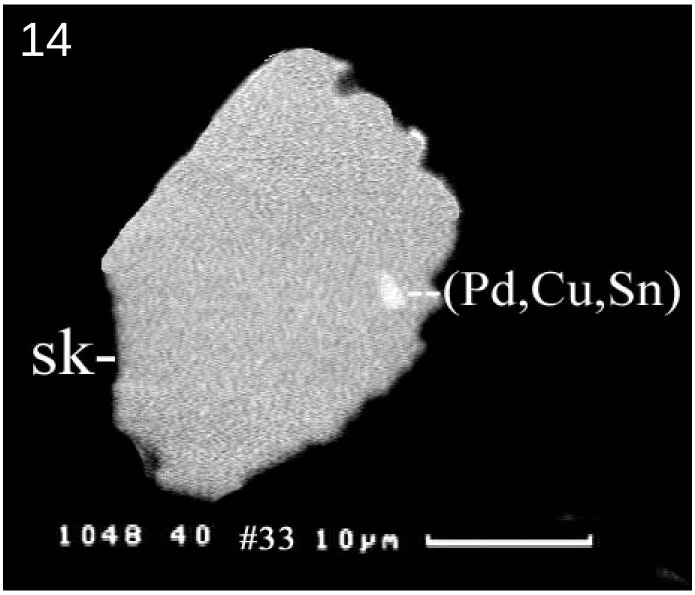

9
zv-
\sk
10µm
1048 <40 #57

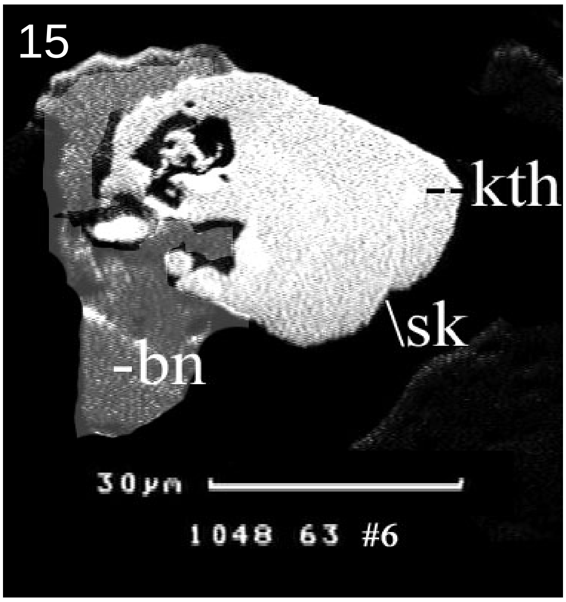

10
bn
--at
sk/
10µm
1048 <40 #64

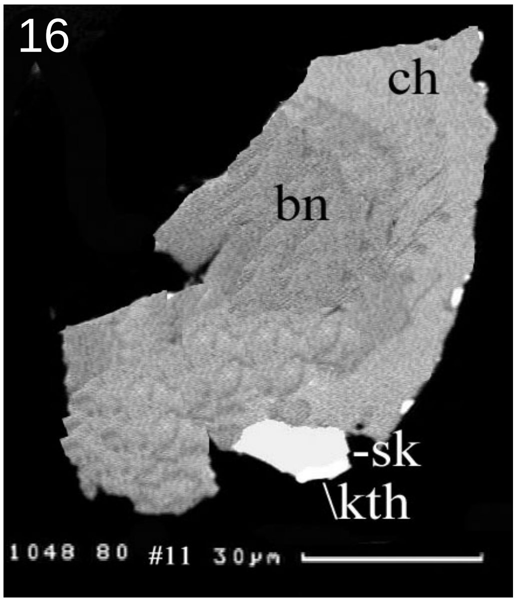

11
/ilm
/at
-sk
1048 40 #30
10µm

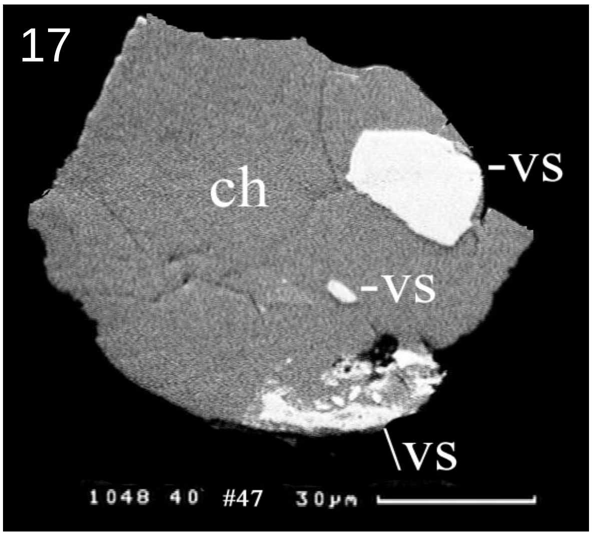

12
bn-
at---
\sk
10µm
1048 <40 #59

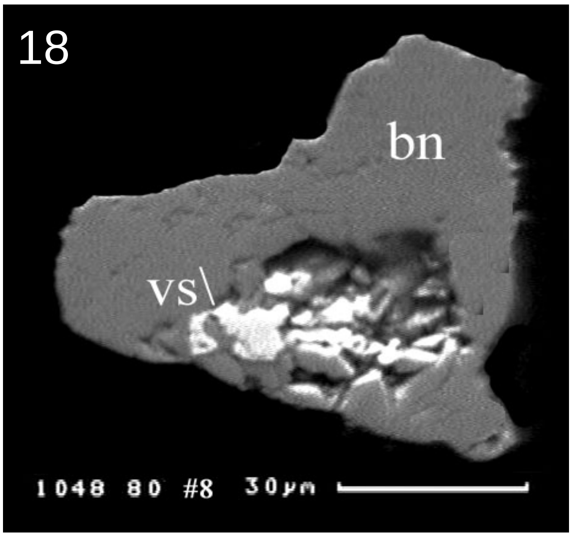

13
sk-
at-
30µm
1048 63 #1

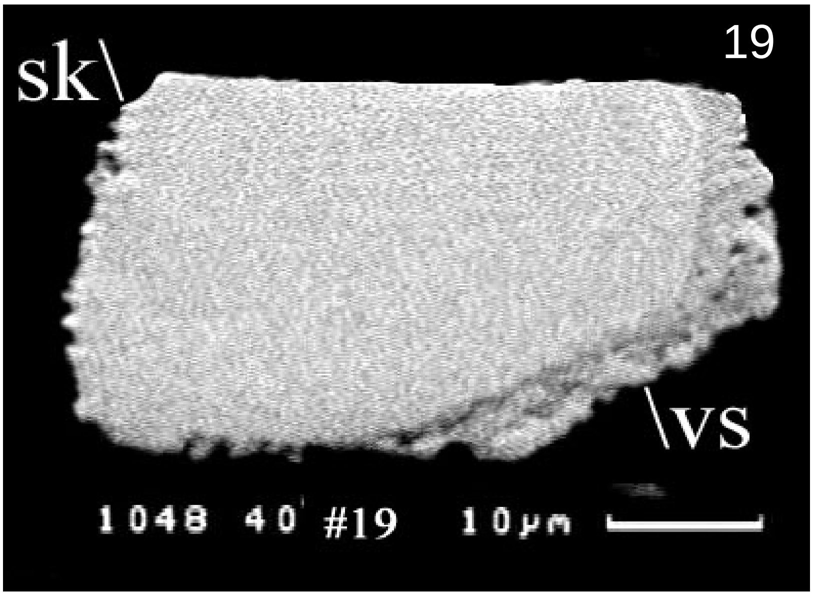

14
--(Pd,Cu,Sn)
sk-
1048 40 #33 10µm


15
--kth
\sk
-bn
30µm
1048 63 #6


16
ch
bn
-sk
\kth
1048 80 #11 30µm


17
-vs
ch
-vs
\vs
1048 40 #47 30µm


18
bn
vs\
1048 80 #8 30µm

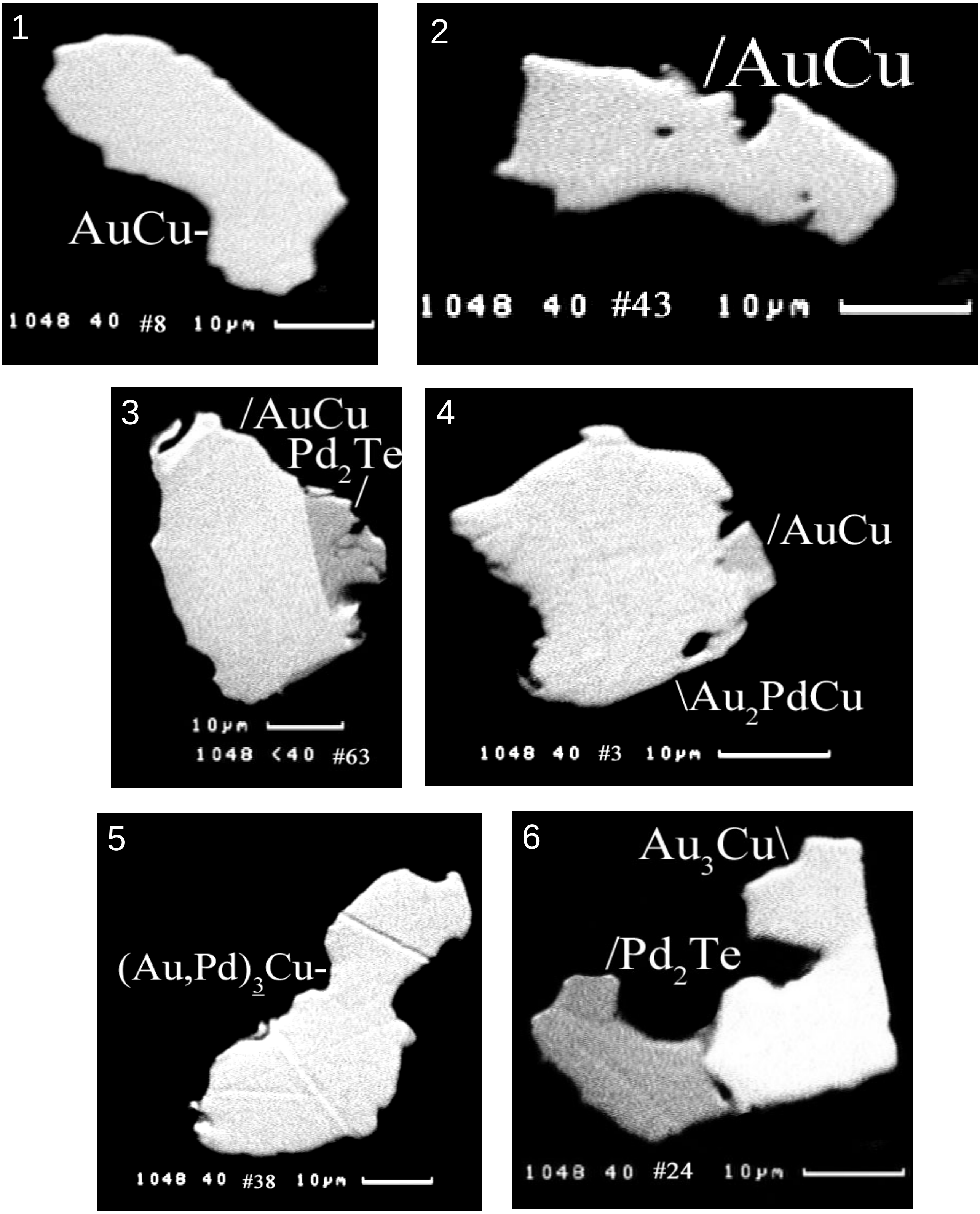


19
sk\
\vs
1048 40' #19 10μm

Plate 7

Grains of gold minerals – tetra-auricupride (images 1-4) and $(Au,Pd)_3Cu$ (images 4-6) in the heavy mineral concentrates of sample 90-24 1048; polished section, SEM-image (BIE).

Abbreviations: AuCu: tetra-auricupride; Pd_2Te: unnamed phase; Au_3Cu and $(Au,Pd)_3Cu$: auricupride


1
AuCu-
1048 40 #8 10μm
2
/AuCu
1048 40 #43 10μm
3
/AuCu
Pd_2Te
/
10μm
1048 <40 #63
4
/AuCu
\Au_2PdCu
1048 40 #3 10μm
5
$(Au,Pd)_3Cu$-
1048 40 #38 10μm
6
Au_3Cu\
/Pd_2Te
1048 40 #24 10μm