DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/96

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

Part 17: Sample 90-24 1059

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

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

G E U S

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/96

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

Part 17: Sample 90-24 1059

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

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

GEUS

Abstract

The report presents the results of mineralogical investigations of the sample 90-24 1059 covering the interval from 1059 to 1060 m in core 90-24 from the Skaergaard mineralisation. The sample collects the lower part of Pd5, the main PGE level in the mineralisation. Assays from the interval give an average of 1200 ppb Pd, 30 ppb Au, and 110 ppb Pt for this interval.

The 1100 g 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 had 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 and followed by wet magnetic separation. The magnetic fractions proved not contain precious metal grains.

The non-magnetic part of every grain size fraction was hydroseparated using the computer controlled hydroseparator CNT-HS-11. The resulting concentrates were mounted as monolayer polished sections These polished sections and one polished section from a chip of the core 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 frozen melt droplets. They contain one or more of the Cu-sulphides bornite, chalcosine, and digenite. Several of the droplets and sulphide grains contain inclusions of a variety of PGMs. A representative selection of PGMs in 102 grains was studied in detail. The dominating precious metal mineral is skaergaardite (Pd,Pt,Au)(Cu,Fe,Zn) (95.8 vol. %). The balance is made by minor nielsenite $PdCu_3$ (2.2 vol. %), (Cu, Pd) alloy (1.6 vol. %), vasilite $(Pd,Cu)_{16}S_7$ (0.2 vol. %), (Pd,Cu,Sn) alloy (0.2 vol. %) and kethconnite Pd_3Te (<0.1 vol. %). The grain size of the precious metal minerals (ECD) varies from 2 to 55 µm with an average of 21 µm.

The average composition of skaergaardite (analyses from 85 grains) is (wt. %): Pd 57.9, Pt 2.1, Au 2.1, Cu 30.9, Fe 3.8, Zn 0.8, Sn 0.6, Te 0.5, Pb 0.6, Total 99.6; The formula is:

$$(Pd_{0.95}Pt_{0.02}Au_{0.02})_{0.99}(Cu_{0.85}Fe_{0.12}Zn_{0.02}Sn_{0.01}Te_{0.01}Pb_{0.01})_{1.02}.$$

The estimated bulk compositions of the sample (assays in brackets) are (ppb): Pd 1250 (1200), Au 45 (30), Pt 45 (110). Pt and Au are shared between skaergaardite and (Cu,Pd) alloy.

The observed intergrain relations suggest that all PGMs and the base metal sulphides belong to a single paragenesis. The sulphide melt droplets contain rare droplets of PGMs and 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 which separated from the sulphide melt as immiscible metal melt.

.

Introduction

The report describes the mineralogy of sample 90-24 1059 from the lower part of Pd5 level in the “Platinova Reef” of the Skaergaard intrusion. Sample 90-24 1059 collects interval between 1059 and 1060 m in the core. The core has previously been sampled for other purposes and the sample collects 1/3 of the diameter of the preserved core. Assays give 1200 ppb Pd, 30 ppb Au, and 110 ppb Pt for this interval (Watts, Grifis & McOuat, 1991)

The mineralogical report is based on the data obtained from monolayer samples of concentrates obtained using the patented Hydroseparator CNT-HS-11 and one polished section of the gabbro. The sections were studied using electron microscopy and electron microprobe analysis (Camscan-4DV, Link AN-10 000). The report gives the grain characteristics, the parageneses and the compositional variation within the identified groups of minerals of the host rock, the sulphides droplets, and the alloys.

The investigation was carried out in 2006.

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003). The heavy mineral concentrates, enriched in precious metal minerals using the patented, computer controlled Hydroseparator CNT-HS-11 and patented glass separation tube (GST) (Rudashevsky & Rudashevsky , 2006 and 2007).

One polished section was prepared from chip of core. All the. remaining material was crushed to –125 μm. After complete grinding, the sample was sieved under water (wet sieving) into the following fractions: <40 μm (405 g), 40-63 μm (150 g), 63-80 μm (59 g), 80-125 μm (288 g) and >125 μm (78 g) and followed by wet magnetitc separation.

The remaining non-magnetitc material of the fractions fractions <40 μm, 40-63 μm, 63-80 μm, 80-125 μm were then processed through hydroseparator CNT-HS-11 and the resulting concentrates were mounted in several monolayer polished sections.

Results

Rock forming minerals and sulphide mineralogy

Silicates and FeTi-oxides

The silicates and FeTi- oxides related to the observed sulphides are: 1) *plagioclase*, An_{45-48} (Table 1, analyses 1-3); 2) *monoclinic ferrous pyroxene*, Mg# = 0.62-0.66 (Table 1, analyses 4-6); 3) *orthorhombic ferrous pyroxene*, Mg# = 0.51-0.52 (Table 1, analyses 7-9); 4) *Fe-rich olivine*, Mg# = 0.46-0.49 (Table 1, analyses 10-12); Fe-Ti oxides including 5) *ilmenite* (Table 1, analyses 13-15) and 6) *titaniferous magnetite* (Table 1, analyses 16-18). 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, 2). At the contact between pyroxenes and Fe-Ti-oxides these aggregates are rimmed by fFe-rich olivine and anorthite-rich plagioclase (Plate 1, #1-3, 5).

The bulk rock is quite “dry”. No minerals containing volatile components were found the thin section of the gabbro (Plate 1). However, volatile-bearing minerals (chamosite and calcite) were identified in sulphide globules in the heavy mineral concentrates (Plate 2, #7).

Sulphides

The host gabbro is relatively poor in sulphides. A search in the thin section only gave a few 10-100 µm sized, irregular or droplet-like sulphide grains composed of bornite, chalcosine, and digenite The grains are enclosed mostly in pyroxene aggregates (Plate 1, #5-8).

The nonmagnetic heavy mineral concentrates are ilmenite-rich products (> 95 % ilm) enriched in grains of sulphides and PGMs (Fig.1). The sulphides form irregular aggregates (Plate 2, #1, 18-24 etc), and microglobules up to 0.1 mm in size. (Plate 2, #3, 4, 9; Plate 3, #1, 8-11 etc).

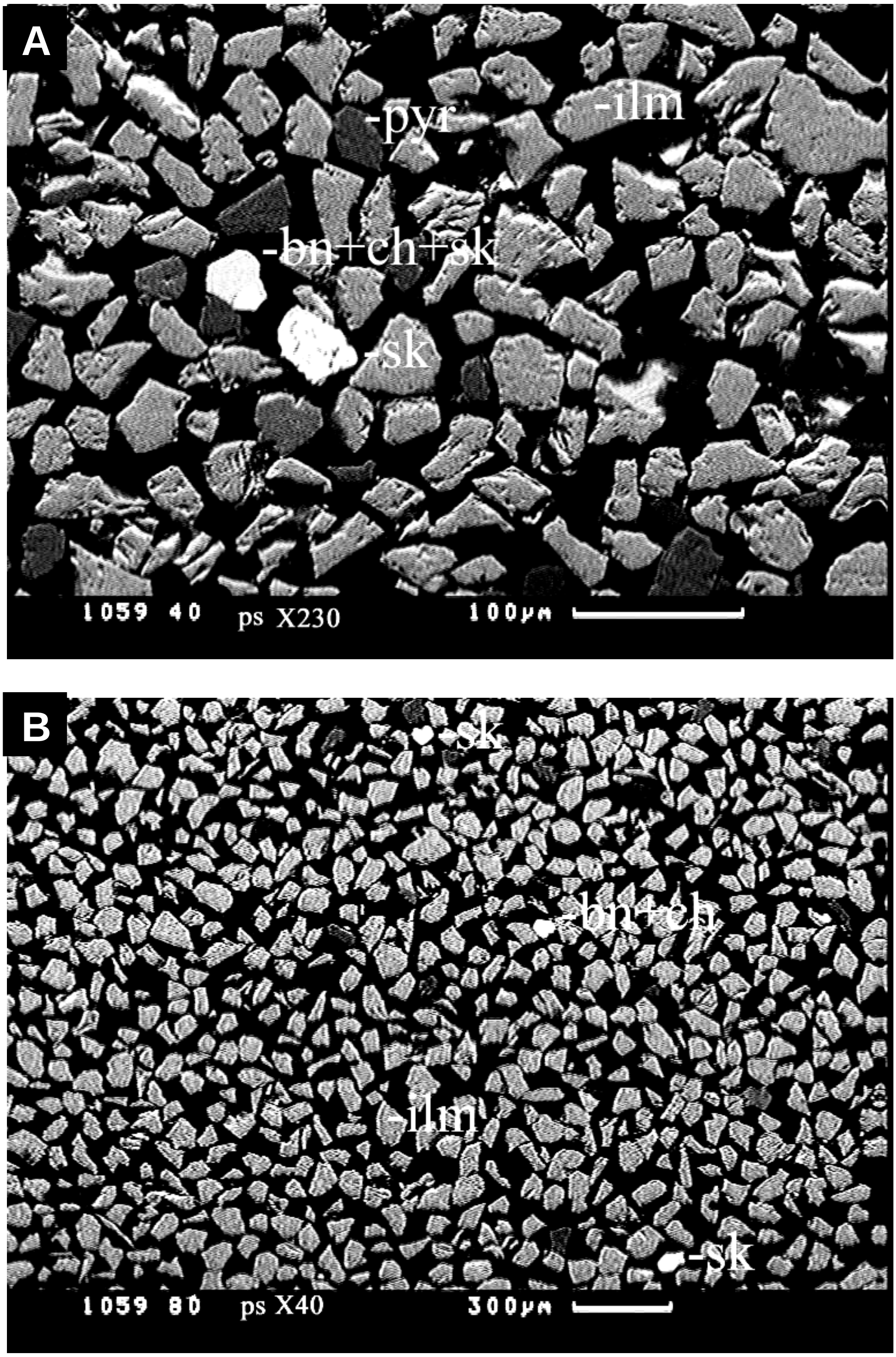


Fig 1. Polished sections of monolayer sample of heavy mineral HS-concentrates of sample 90-24 1059: A) grain size fraction <40 μm; B) grain size fraction 63-80 μm), sample 90-24 1059, SEM-images (BIE). Abbreviations: ilm – ilmenite, sk – skaergaardite, bn – bornite, ch – chalcosine grop minerals, pyr – pyroxenes.

The sulphides are dominated by bornite and chalcosine group minerals (see Plates 1, #5-8; Plate 2). The volume ratio varies significantly from grain to grain (see Plate 2). Inside microglobules bornite and chalcosine group minerals form classical exsolution textures (Plate 2, #3-6, 8-24; Plate 3, #1-11, 13, 14 etc). Compositions of bornite (Table 2, analyses 1, 4, 6, 8, 9), chalcosine (Table 2, analyses 2, 3, 5, 11) and digenite (Table 3, analyses 7, 10) are all near- stoikiometric.

PGMs: recovery, grain size and relations to host rock

Recovery

No PGMs were found during SEM studies of the polished section of gabbro (90-24, 1059). However, the heavy mineral concentrates have yielded many PGM grains. A representative selection of 102 grains of a wide size range (from <40 μm up to 63-80 μm) was studied in detail. Six different PGMs are recorded in the sample 90-24 1059 and include:

1. *Skaergaardite* (Pd,Pt,Au)(Cu,Fe,Zn,Sn,Te,Pb) – 98 grains,
2. *Nielsenite* $Pd(Cu,Fe)_3$ –2 grains
3. *(Cu,Pd,Pt,Au) alloy* – 3 grains;
4. *(Pd,Cu,Sn) alloy* – inclusions in 1 grain;
5. *Vasilite* $(Pd,Cu)_{16}S_7$ – 1 grain;
6. *Keithconnite* Pd_3Te *(?)* – 1 grain.

The volumetric proportions are calculated from the area of grains of these minerals and shown in Table 3 and 4 and in Figure 2.

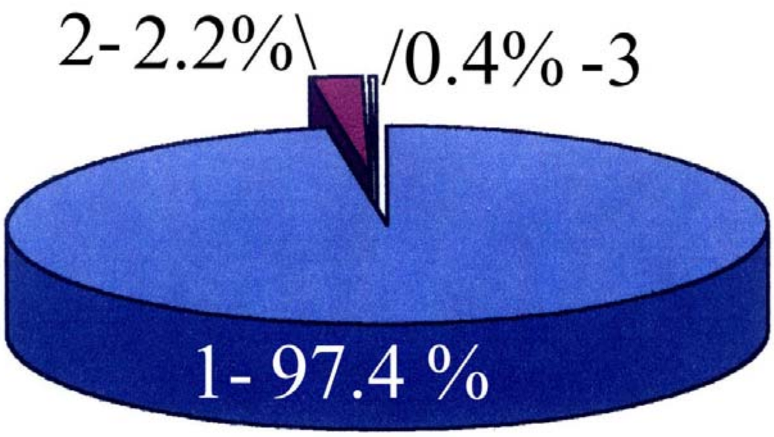


Fig. 2. The relative contents of PGMs in sample 90-24 1059 (see Table 4).: 1) skaergaardite+(Cu,Pd) alloy; 2) nielsenite; 3): keithconnite, vasilite and (Pd,Cu,Sn) alloy.

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 with an average of 21 µm (Table 3; Fig. 3).

Grain size, µm	Number of grais
0-10	17
10-20	35
20-30	31
30-40	13
40-50	1
50-60	5

The histogram of grain sizes (Fig. 3) show the lognormal distribution for the statistical selection (n=102). According to this histogram, size of PGM grains are distributed as follows:

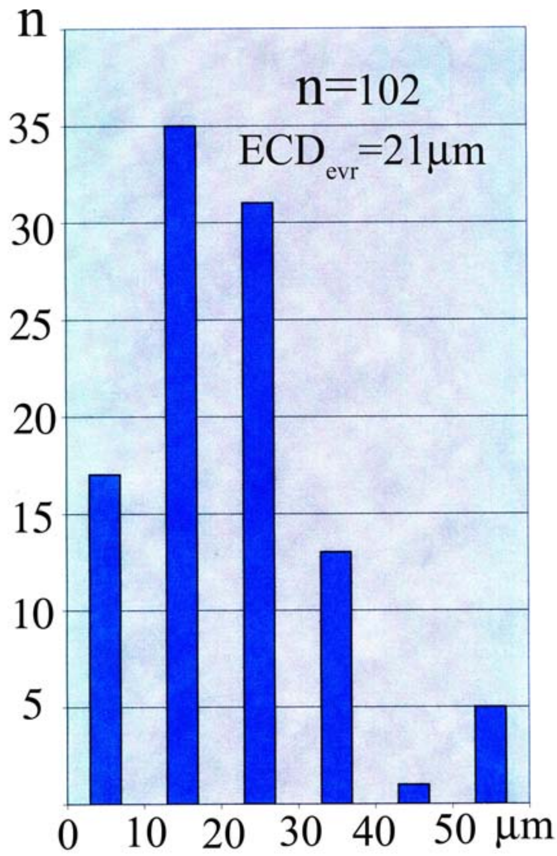


Fig 3.Histogram of the grain size distribution of PGMs (n=102), in the heavy mineral concentrates of sample 90-24 1059.

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

Petrographic observations

The almost perfect separation of the accessory minerals and phases has been achieved by gentle crushing/disintegration of the studied sample. The method leads of the primary grain size, as well as recovery of the most important information for the reconstyruction of the genesis of the minerals and the phases. The concentrates provide sufficient information for the reconstruction of the primary shapes and sizes of accessory minerals, their mineral paragenesises and the relationship to the rock-forming minerals.

In the heavy concentrates of the sample 90-24, 1059 (n=102) the precious metal mineral grains occur in the following mineral associations (Fig. 4; Table 5):

Table 5

Association	**PGM-grains, vol. %**
L	34.8
bms-L	26.9
bms	31.9
sag-L	2.9
sag	0.2
ag-L	2.2
ag	1.1

Different associations of PGM grains in heavy concentrates of the sample 90-24, 1059.
L: completely liberated (free) particles; bms-L: liberated particles with <10 % attached base metal sulphides; bms: intergrowths with base metal sulphides (bornite, chalcosine, di-genite); sag-L: sulphide and gangue attached to PGMs, but <10%; sag: sulphide and gangue (ilmenie and olivine) attached to PGMs; ag-L: precious metal minerals attached to gangue, but <10% gangue (ilmenite); ag: precious metal minerals attached to gangue.

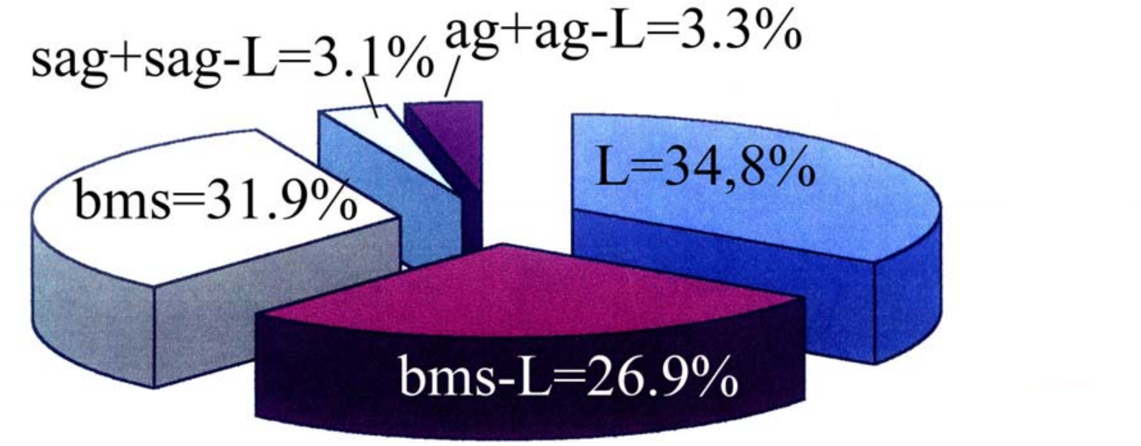


Fig. 4. PGMs grouped by associations – a, b (sample 90-24 1059); see Table 4. L: completely liberated (free) particles; bms-L: liberated particles with <10 % attached base metal sulphides; bms: intergrowths with base metal sulphides (bornite, chalcosine, digenite); sag-L: sulphide and gangue attached to PGMs, but <10%; sag: sulphide and gangue (ilmenie and olivine) attached to PGMs; ag-L: precious metal minerals attached to gangue, but <10% gangue (ilmenite); ag: precious metal minerals attached to gangue.

Completely liberated PGM grains constitute 34.8%f of the precious metal grains in the heavy mineral concentrate. Grains attached to bms (bms+bms-L+sag+sag-L associations) dominate and constitute 67.9% (see Fig 4,b). 3.3% of the PGMs are attached to gangue (ag and ag-L associations).

Based on the observations in the SEIs, the precious metal minerals in the heavy mineral concentrates can be divided into the following groups 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, sag-L, ag** 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,Pt,Au)(Cu,Fe,Zn,Sn,Te,Pb)

Description

Skaergaardite (Rudashevsky et al., 2004) is the dominant Pd mineral in heavy concentrates of the sample 90-24 1059 (95.8 vol.%). It is found in the heavy mineral concentrates in the following forms:

1. liberated (free) grains: **L** (Plate 5);
2. intergrowths with base metal sulphides (bornite, chalcosine, digenite) - **bms** (Plate 3, #1-41; Plate 6,#5); **bms-L** (Plate 3, #42-59);
3. intergrowths with sulphide and gangue (ilmenite, olivine): **ag** (Plate 4, #1); **sag, sag-L** (Plate 4, #3-5);
4. intergrowths with other PGMs including vasilite (Plate 6, #4) and (Pd,Cu,Sn) (Plate 6, #5).

Beside occurring as liberated grains, skaergaardite is also recorded in association with base metal sulphides (see Plate 3 and Plate 4, #3-5). The skaergaardite-bearing sulphide grains form droplets (Plate 3, #1, 7-11, 16 etc) and occur as irregular grains and aggregates (Plate 3, #3, 2-6, 12-15, 17-41 etc). Usually skaergaardite grains are localized at the margins of sulphide globules (Plate 3, #1-15, 18-29 etc).

Skaergaardite grains occur as:

1. isometric droplet-like grains with the rounded outlines (Plate 3, #1-7. 12-16, 49-54; Plate 5, #1-5 etc);
2. euhedral crystals or partially euhedral grains (Plate 3, #8-11, 17-47 etc);
3. irregular grains and aggregates (Plate 3, #29-37, 55-60; Plate 5, #6-33 etc).

The grain size of skaergaardite ais from 2 to 55 μm with an average of 22 μm (Table 5).

Composition

The composition of skaergaardite is constrained by 86 analyses from 85 grains (Table 6). The average composition (Table 6, analysis # 87) is (wt. %): Pd 57.9, Pt 2.1, Au 2.1, Cu 30.9, Fe 3.8, Zn 0.8, Sn 0.6, Te 0.5, Pb 0.6, Total 99.6. The composition corresponds to the formula:

$$(Pd_{0.95}Pt_{0.02}Au_{0.02})_{0.99}(Cu_{0.85}Fe_{0.12}Zn_{0.02}Sn_{0.01}Te_{0.01}Pb_{0.01})_{1.02}.$$

Typical substitutions in skaergaardite are: Pt up to 12.6 % (Table 6, analysis 34), Au up to 15,1 % (Table 6, analysis 53), Fe up to 7.0 % (Table 6, analysis 46), Zn up to 6.4 % (Table 6, analysis 81), Sn up to 10.5 % (Table 6, analysis 69), Te up to 4.4 % (Table 6, analysis 8), Pb up to 6.4 % (Table 6, analysis 5).

Pt and Au concentrations in skaergaardite (n=86) are distributed as follows (see basic data in table 6):

Interval, Pt wt %	Number of analyses, Pt	Interval, Au wt %	Number of analyses, Au
0-1	37	0-1	41
1-3	26	1-3	25
3-5	13	2-3	9
5-7	2	5-7	4
7-9	6	7-9	3
9-11	0	9-11	0
11-13	2	11-13	3
13-15	0	13-15	1

Nielsenite $Pd(Cu,Fe)_3$

Two grains of nielsenite (2.2 vol % of PGMs) were found in heavy mineral concentrates of sample 90-24 1059 (see Table 4). Nielsenite is associated to (Cu,Pd) alloy and chalcosine (Plate 6, #1, 2). The grain size of nielsenite is from 22 to 29 μm, with an average of 25 μm. The composition of nielsenite is near- stoikiometric $PdCu_3$ (Table 7, analyses 2, 4).

(Cu,Pd) alloy

As opposed to skaergaardite and nielsenite, (Cu,Pd) alloy is not stoikiometric. Three grains of this alloy (1,6 vol % of PGMs) were found in heavy mineral concentrates of sample 90-24, 1059 (see Table 4). It is associated to nielsenite, chalcosine and ilmenie (Plate 6, #1, 3). The sizes of its grains vary from 9 to 26 μm, with an average of 13 μm. The composition of (Cu,Pd) alloy is shown in the Table 7 (analyses 1, 3). (Cu,Pd) alloy shows Pt (1.6-3.3 wt.%) and Au (2-3.1 wt.%) substitutions.

Rare PGMs

Other 3 PGMs were found in the heavy mineral concentrates (0.4 vol. % all together)

(Pd,Cu,Sn) alloy

Six fine inclusions of (Pd,Cu,Sn) alloy (1-6 μm in size with an average of 3 μm) were identified (Table 7, analysis 5) inside a grain-intergrowth composed of skaergaardite and bornite (Plate 6, #5). It represents ~0.2 vol. % of all the PGMs in sample 90-24 1059 (see Table 4).

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

One grain of vasilite was identified. It occurs in association with skaergaardite only – (Plate 6, #4). It has an irregular shape and is 12 μm in size. The composition of vasilite corresponds to the stoikiometric formula $(Pd,Cu)_{16}S_7$ (Table 7, analysis 6). It represents ~0.2 vol. % of the PGMs in sample 90-24 1059 (see Table 4).

Keithconnite Pd_3Te(?)

Keithconnite Pd_3Te is seen under the SEM as fine (2 μm) inclusion in a sulphide globule composed of bornite and chalcosine (Plate 6, # 6). It represents <0.1 vol. % of all the PGMs in the sample (see Table 4).

Bulk composition of PGMs of the sample 90-24 1059

The relative concentrations of Pd, Au and Pt in sample 90-24 1059 can be calculated from the total concentration of precious metals, the measured recovery, the modal proportions and the chemical 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 1250 (1200), Au 45 (30), Pt 45 (110) - Pt and Au are concentrated in skaergaardite and partly in (Cu,Pd) alloy.

Discussion

PGM-paragenesis

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

Order of crystallization

The Cu-Fe sulphides and PGMs are synchronous and crystallized later than rock-forming minerals: plagioclase, clinopyroxene, orthopyroxene, ilmenite and titanomagnetite.

The characteristic droplet shape of both - PGMs and host sulphides suggest that they represent two immiscible melts: 1) Cu-Fe sulphide melt and 2) immiscible metal melt, enriched by Pd, Cu, Pt and Au.

Summary

1. A total of 102 PGM-grains were enriched into the heavy mineral concentrates produced from sample 90-24, 1059 (1.1 kg) using the hydroseparator CNT-HS-11.

2. The dominant precious metal mineral is skaergaardite (Pd,Pt,Au)(Cu,Fe,Zn,Sn,Te,Pb) with 95.8 vol. %. In addition, 5 other PGMs (in total ~ 4.2 vol. %) were identified and include nielsenite (2.2 vol. %), (Cu,Pd) alloy (1.6 vol. %), (Pd,Cu,Sn) alloy (0.2 vol. %), vasilite $(Pd,Cu)_{16}S_7$ (0.2 vol. %) and keithconnite Pd_3Te (<0.1 vol. %).

3. The estimated bulk composition of the sample (assays of whole rock in brackets) is (ppb): Pd 1250 (1200), Au 45 (30), Pt 45 (110). Pt and Au are distributed in skaergaardite and partly in (Cu,Pd) alloy.

4. The sulphide droplets contain 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.

5. The sample 90-24 1059 is very similar to the earlier studied sample 90-24 1062 in its PGE composition, and it has also similar PGE distribution between PGMs.

References

Nielsen, T.F.D., Rasmussen, H., Rudashevsky, N.S., Kretser, Yu.L., Rudashevsky, V.N. 2003. PGE and sulfide phases of the precious metal mineralisation of the Skaergaard intrusion. Part 2: sample 90-24, 1057.Geol. Surv. Denmark & Greenland report **2003/48**; 20 pp.

Rudashevsky, N.S., MacDonalds, A.M.Cabri, L.J., Nielsen, T.D.F., Stanley, C.J., Kretzer, Yu.L., Rudashevsky, V. N. 2004. Skaergaardite, PdCu, a new platinum group intermetallic mineral from the Skaergaard intrusion, Greenland. Mineralogical Magazine, 2004, **68 (4)**, 615-632.

Watts, Griffis & McOuat 1991: 1990 Skaergaard project, Platinova/Corona concession, East Greenland, 55 pp. with appendixes in volumes 2A, 2B, 3A and 3B (in archive of Danmarks og Grønlands Geologiske Undersøgelse, GRF no. 20848).

TABLES

Table 1. Compositions of silicates and FeTi- oxides in sample 90-24 1059

	Plagioclase			Clinopyroxene			Orthopyroxene			Olivine			Ilmenite			Titanomagnetite		
Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
wt%																		
SiO_2	56.3	56.4	55.7	50.2	50.8	51.0	50.7	51.1	51.5	34.2	34.6	34.4	-	-	-	-	-	-
TiO_2	-	-	-	0.7	0.5	0.4	0.3	0.2	0.2	-	-	-	51.4	51.2	50.9	12.6	13.4	12.0
Al_2O_3	26.8	27.1	27.3	1.4	1.0	1.1	0.5	0.3	-	-	-	-	-	-	-	2.5	2.8	3.2
V_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.4	0.6	1.9	1.8	1.9
Fe_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	3.3	3.8	4.2	40.6	38.0	40.8
FeO	-	-	-	14.1	12.4	13.0	29.4	29.1	29.0	43.6	42.2	42.1	43.1	42.1	41.2	42.5	42.1	41.9
MnO	-	-	-	0.4	0.2	0.3	0.7	0.7	0.6	0.6	0.6	0.5	0.3	0.5	0.5	0.3	0.4	0.3
MgO	-	-	-	12.8	13.5	12.3	16.9	17.3	17.7	21.1	22.4	22.4	1.5	1.9	2.3	0.5	0.9	0.6
CaO	9.7	10.1	9.9	20.4	20.9	21.7	1.3	1.3	1.0	-	-	-	-	-	-	-	-	-
Na_2O	5.4	5.6	6.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K_2O	0.4	0.3	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
sum	98.6	99.5	99.4	100.0	99.3	99.8	99.8	100.0	100.0	99.5	99.7	99.3	100.0	99.5	99.6	100.9	99.4	99.9
Proportions																		
SiO_2	2.55	2.55	2.53	1.92	1.94	1.95	1.97	1.98	1.99	1.00	1.00	1.00	-	-	-	-	-	-
TiO_2	-	-	-	0.02	0.02	0.01	0.01	0.01	0.01	-	-	-	0.97	0.96	0.95	0.35	0.38	0.33
Al_2O_3	1.43	1.44	1.46	0.06	0.05	0.05	0.03	0.01	-	-	-	-	-	-	-	0.11	0.13	0.14
V_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.01	0.01	0.06	0.06	0.06
Fe_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	0.06	0.07	0.08	1.13	1.07	1.13
FeO	-	-	-	0.45	0.39	0.41	0.95	0.94	0.93	1.07	1.02	1.02	0.90	0.88	0.86	1.31	1.31	1.30
MnO	-	-	-	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MgO	-	-	-	0.73	0.77	0.70	0.98	1.00	1.02	0.92	0.96	0.97	0.06	0.07	0.08	0.03	0.05	0.03
CaO	0.47	0.49	0.48	0.84	0.85	0.89	0.05	0.05	0.04	-	-	-	-	-	-	-	-	-
Na_2O	0.56	0.49	0.54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K_2O	0.02	0.02	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
O-basis	8	8	8	6	6	6	6	6	6	4	4	3	3	3	3	4	4	4
cation basis																		
An%	0.46	0.50	0.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg#	-	-	-	0.62	0.66	0.63	0.51	0.52	0.52	0.46	0.48	0.49	-	-	-	-	-	-

Table 2. Compositions of base metal sulphides in the heavy mineral concentrates of sample 90-24 1059

An	Grain	Association	Mineral	wt% Cu	wt% Fe	wt% S	wt% Total	*Proportions Cu*	*Proportions Fe*	*Proportions S*	*Proportions Total*
1	80 gr3a	ch+bn	bn	63.3	11.0	25.6	99.9	*5.00*	*0.99*	*4.01*	*10*
2	80 gr4a	bn+ch	ch	79.1	1.1	19.7	99.9	*1.99*	*0.03*	*0.98*	*3*
3	80 gr5a	ch+bn	ch	78.6	0.9	20.4	99.9	*1.96*	*0.03*	*1.01*	*3*
4	80 gr5a	ch+bn	bn	62.8	11.4	25.6	99.8	*4.96*	*1.03*	*4.01*	*10*
5	80 gr7a	ch	ch	79.0	0.6	20.4	100.0	*1.97*	*0.02*	*1.01*	*3*
6	80 gr8a	bn	bn	63.6	10.7	25.8	100.1	*5.01*	*0.96*	*4.03*	*10*
7	80 gr1	sk+dg+bn	dg	75.6	1.8	21.5	98.9	*8.80*	*0.34*	*4.96*	*14*
9	80 gr1	sk+dg+bn	bn	61.6	10.8	25.9	98.3	*4.92*	*0.98*	*4.10*	*10*
9	40 gr4	sk+bn+dg	bn	63.2	10.9	25.5	99.6	*5.01*	*0.98*	*4.01*	*10*
10	40 gr23a	dg+bn	dg	76.5	1.4	21.6	99.5	*8.85*	*0.19*	*4.96*	*14*
11	40 gr57	sk+ch	ch	79.2	0.9	19.7	99.8	*1.97*	*0.03*	*1.00*	*3*

Abbreviations: ch: chalcosine; bn: bornite; dgn: digenite; sk: skaergaardite.

Table 3. The size of precious metal grains in the heavy mineral concentrates of sample 90-24 1059

N	Gr#	host/assoc	Assoc.type	Mineral	Note	Area μm^2	ECD, μm
1	40-11	sk	L	sk		1020	36
2	40-10	nls+ch	bms	nls		363	22
3	40-13	sk+bn+ilm	sag-L	sk		1343	41
4	40-14	sk+ch+bn	bms	sk		185	15
5	40-15	sk	L	sk		251	18
6	40-16	sk+bn+ch	bms-L	sk		606	28
7	40-17	sk+bn+ch	bms	sk		344	21
8	40-18	sk+bn	bms-L	sk		1005	36
9	40-19	sk+ch	bms-L	sk		1016	36
10	40-1	sk+bn	bms-L	sk		947	35
11	40-20	sk	L	sk		448	24
12	40-21	sk+bn	bms-L	sk		165	14
13	40-22	sk+bn+ch	bms	sk		13	4
14	40-23	sk+ch+bn	bms	sk		54	8
15	40-24	sk+bn	bms	sk		421	23
16	40-25	sk	L	sk		421	23
17	40-26	sk+bn+ch	bms	sk		574	27
18	40-27	sk	L	sk		179	15
19	40-28	sk+bn+ch	bms	sk		194	16
20	40-29	sk+ch+bn+ol	sag	sk		34	7
21	40-2	sk	L	sk		236	17
22	40-30	sk	L	sk		98	11
23	40-30-2	sk+ch	bms	sk		205	16
24	40-31	sk+ch+bn	bms	sk		6	3
25	40-32	sk	L	sk		412	23
26	40-33	sk	L	sk		183	15
27	40-34	sk	L	sk		126	13
28	40-35	sk	L	sk		551	26
29	40-36	sk+bn+ch	bms	sk		97	11
30	40-37	sk+bn	bms	sk		102	11
31	40-38	sk+bn	bms-L	sk		792	32
32	40-39	sk	L	sk		166	15
33	40-3	sk+bn+ch	bms-L	sk		226	17
34	40-41	sk	L	sk		121	12
35	40-42	sk	L	sk		155	14
36	40-43	sk+ch+bn	bms	sk		98	11
37	40-44	sk+bn+ch	bms	sk		4	2
38	40-45	sk+bn+ch	bms	sk		590	27
39	40-46	sk+bn	bms-L	sk		359	21
40	40-47	sk+bn	bms-L	sk		381	22
41	40-48	sk	L	sk		772	31
42	40-49	sk	L	sk		679	29
43	40-4	sk+dg+bn	bms	sk		2	2
44	40-50	sk	L	sk		2193	53
45	40-51	sk+(Pd,Cu,Sn)+bn	bms	Total		260	18
46	40-51	sk+(Pd,Cu,Sn)+bn	bms	sk		170	15
47	40-51	sk+(Pd,Cu,Sn)+bn	bms	(Pd,Cu,Sn)	6grains	90	11
48	40-52	sk+bn	bms	sk		169	15
49	40-53	sk	L	sk		655	29
50	40-54	sk+bn+ch	bms	sk		43	7
51	40-55	sk+bn	bms	sk		646	29

Table 3 continued

N	Gr#	host/assoc	Assoc.type	Mineral	Note	Area μm^2	ECD, μm
52	40-56	sk+bn+ch	bms	sk		156	14
53	40-57	sk+ch	bms-L	sk		882	34
54	40-58	nls+(Cu,Pd)+ch	bms-L	Total		919	34
55	40-58	nls+(Cu,Pd)+ch	bms-L	nls		674	29
56	40-58	nls+(Cu,Pd)+ch	bms-L	(Cu,Pd)		166	15
57	40-58	nls+(Cu,Pd)+ch	bms-L	(Cu,Pd)		69	9
58	40-59	sk	L	sk		305	20
59	40-5	sk	L	sk		665	29
60	40-60	sk+bn	bms-L	sk		686	30
61	40-61	sk	L	sk		396	22
62	40-62	sk+ch+bn	bms-L	sk		507	25
63	40-63	sk	L	sk		394	22
64	40-64	sk+vs	L	Total		320	20
65	40-64	sk+vs	L	sk		207	16
66	40-64	sk+vs	L	vs		113	12
67	40-65	sk+ch	bms-L	sk		68	9
68	40-66	sk+ch+bn	bms	sk		40	7
69	40-67	sk	L	sk		433	23
70	40-68	sk	L	sk		125	13
71	40-69	sk	L	sk		113	12
72	40-70	sk+bn+ch	bms	sk		267	18
73	40-71	sk	L	sk		215	17
74	40-72	sk	L	sk		239	17
75	40-76	(Cu,Pd)+ilm	ag	(Cu,Pd)		520	26
76	40-77	sk	L	sk		802	32
77	40-78	sk	L	sk		184	15
78	40-79	sk+ch+ilm	sag	sk		77	10
79	40-7	sk+ilm	ag-L	sk		1017	36
80	40-80	sk+ch	bms-L	sk		504	25
81	40-81	sk+bn+ch	bms	sk		20	5
82	40-82	sk+ch	bms	sk		110	12
83	40-83	sk+bn	bms-L	sk		966	35
84	40-84	sk+bn+ch	bms	sk		980	35
85	40-8	sk+bn	bms-L	sk		286	19
86	40-9	sk	L	sk		387	22
87	63-10	sk+bn+ch	bms	sk		117	12
88	63-11	sk+bn+ch	bms	sk		454	24
89	63-12	sk+bn+ch	bms	sk		97	11
90	63-13	sk+bn+ch	bms	sk		151	14
91	63-14	sk	L	sk		489	25
92	63-15	sk+ch+bn	bms	sk		650	29
93	63-1	kth+bn+ch	bms	kth		4	2
94	63-3	sk+bn+ch	bms	sk		66	9
95	63-4	sk+bn+ch	bms	sk		117	12
96	63-5	sk+bn+ch	bms	sk		768	31
97	63-6	sk	L	sk		367	22
98	63-7	sk+bn+ch	bms-L	sk		2385	55
99	63-8	sk	L	sk		2263	54
100	80-10	sk+ch+bn	bms	sk		704	30
101	80-1	sk+dg+bn	bms	sk		15	4
102	80-2	sk+bn+ch	bms	sk		9	3
103	80-3	sk+bn+ch	bms	sk	4 grains	42	7
104	80-4	sk+bn+ch	bms	sk		460	24
105	80-5	sk+bn+ch	bms	sk		242	18

Table 3 continued

N	Gr#	host/assoc	Assoc.type	Mineral	Note	Area μm^2	ECD, μm
106	80-6	sk+ch+bn	bms	sk		7	3
107	80-7	sk+ch+bn	bms	sk		2475	56
108	80-8	sk+bn+ch	bms	sk		2410	55
109	80-9	sk+ch+bn	bms	sk		302	20

Table 4. PGMs in heavy concentrates of sample 90-24 1059

N	Mineral	General formula	Number of grains	Grain size, µm			Vol. %
				min	max	average	
1	Skaergaardite	(Pd,Pt,Au)(Cu,Fe,Zn)	98	2	55	22	95.8
2	Nielsenite	$Pd(Cu,Fe)_3$	2	22	29	25	2.2
3	(Cu,Pd) alloy	(Cu,Pd,Au,Pt)	3	9	26	13	1.6
4	Vasilite	$(Pd,Cu)_{16}S_7$	1			12	0.2
5	(Cu,Pd,Sn) alloy	(Cu,Pd,Sn)	6 in 1	1	6	3	0.2
6	Keithconnite	Pd_3Te	1			2	
	Total						100

Table 5

Enclosed in text

Table 6 Chemical composition and formulas of the skaergaardite in PGM-grains of the heavy concentrates (sample 90-24 1059)

			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	62.9	0.0	1.2	27.3	5.9	1.7	0.0	0.0	0.0	99.7	*1.02*	*0.00*	*0.01*	*0.74*	*0.18*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
2	40 gr2	sk	49.1	2.2	12.5	31.4	2.9	0.0	0.0	1.1	0.0	99.2	*0.85*	*0.02*	*0.12*	*0.91*	*0.09*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
3	40 gr3	sk+bn+ch	54.3	8.3	0.0	29.7	6.0	0.8	0.0	0.0	0.0	99.1	*0.90*	*0.07*	*0.00*	*0.82*	*0.19*	*0.02*	*0.00*	*0.00*	*0.00*	*2.00*
4	40 gr5	sk	55.7	1.1	6.4	31.5	3.7	0.0	0.0	1.4	0.0	99.8	*0.92*	*0.01*	*0.06*	*0.87*	*0.12*	*0.02*	*0.00*	*0.00*	*0.00*	*2.00*
5	40 gr6	sk+ch+bn	57.1	3.9	0.0	30.6	0.9	0.8	0.9	0.0	6.4	100.7	*0.97*	*0.04*	*0.00*	*0.87*	*0.03*	*0.02*	*0.01*	*0.00*	*0.06*	*2.00*
6	40 gr7	sk+ilm	60.5	0.0	3.5	32.7	3.3	0.0	0.0	0.7	0.0	100.6	*0.98*	*0.00*	*0.03*	*0.87*	*0.10*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*
7	40 gr8	sk+bn	61.4	2.6	1.3	30.7	3.9	0.0	0.0	0.0	0.0	100.6	*1.00*	*0.02*	*0.01*	*0.84*	*0.12*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
8	40 gr11	sk	59.1	1.4	0.0	30.9	1.8	0.6	0.0	4.4	1.0	99.7	*0.98*	*0.01*	*0.00*	*0.86*	*0.05*	*0.02*	*0.00*	*0.06*	*0.00*	*2.00*
9	40 gr13	sk+bn+ilm	60.8	0.0	0.0	31.4	0.6	0.0	7.1	0.0	0.0	99.9	*1.00*	*0.00*	*0.00*	*0.86*	*0.02*	*0.00*	*0.12*	*0.00*	*0.00*	*2.00*
10	40 gr14	sk+ch+bn	55.5	6.1	2.2	30.3	5.9	0.0	0.0	0.0	0.0	99.9	*0.91*	*0.05*	*0.02*	*0.83*	*0.18*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
11	40 gr15	sk	56	8.1	0.0	29.0	6.8	0.0	0.0	0.0	0.0	99.8	*0.92*	*0.07*	*0.00*	*0.80*	*0.21*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
12	40 gr16	sk+bn+ch	57.7	1.4	2.5	32.3	3.4	0.7	0.0	1.4	0.0	99.4	*0.94*	*0.01*	*0.02*	*0.88*	*0.11*	*0.02*	*0.00*	*0.02*	*0.00*	*2.00*
13	40 gr17	sk+bn+ch	59.3	0.0	1.4	32.9	2.9	2.4	0.0	0.7	0.0	99.6	*0.95*	*0.00*	*0.01*	*0.88*	*0.09*	*0.06*	*0.00*	*0.01*	*0.00*	*2.00*
14	40 gr18	sk+bn	61.6	0.0	2.1	27.9	5.1	1.7	0.0	0.8	0.0	99.2	*1.01*	*0.00*	*0.02*	*0.76*	*0.16*	*0.04*	*0.00*	*0.01*	*0.00*	*2.00*
15	40 gr20	sk	60.7	1.1	1.3	29.7	4.0	0.0	0.0	2.0	1.1	99.9	*1.00*	*0.01*	*0.01*	*0.82*	*0.12*	*0.00*	*0.00*	*0.03*	*0.01*	*2.00*
16	40 gr21	sk+bn	57.9	4.8	0.9	29.1	5.4	1.0	0.0	0.0	0.0	99.1	*0.95*	*0.04*	*0.01*	*0.80*	*0.17*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
17	40 gr23	sk+ch+bn	50.1	3.0	0.0	30.1	5.1	0.0	0.0	0.0	1.0	99.3	*0.98*	*0.03*	*0.00*	*0.82*	*0.16*	*0.01*	*0.00*	*0.00*	*0.00*	*2.00*
18	40 gr24	sk+bn	57.0	1.4	4.6	31.6	3.7	0.0	0.0	1.1	0.0	99.4	*0.94*	*0.01*	*0.04*	*0.87*	*0.12*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
19	40 gr25	sk	62.3	0.0	0.0	29.3	6.1	1.0	0.0	0.8	0.0	99.5	*0.99*	*0.00*	*0.00*	*0.78*	*0.19*	*0.03*	*0.00*	*0.01*	*0.00*	*2.00*
20	40 gr26	sk+bn+ch	61.0	0.0	1.2	29.3	2.1	1.2	1.9	0.0	2.4	99.1	*1.02*	*0.00*	*0.01*	*0.82*	*0.07*	*0.03*	*0.03*	*0.00*	*0.02*	*2.00*
21	40 gr27	sk	60.2	2.5	0.0	30.5	5.1	1.0	0.0	0.0	0.0	99.3	*0.97*	*0.02*	*0.00*	*0.82*	*0.16*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
22	40 gr28	sk+bn+ch	60.0	1.4	1.6	30.2	5.3	0.0	0.0	0.8	0.0	99.3	*1.00*	*0.01*	*0.01*	*0.84*	*0.13*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*
23	40 gr29	sk+ch+bn+ol	59.9	0.9	0.0	32.1	1.0	0.0	3.0	0.9	1.8	99.7	*0.99*	*0.01*	*0.00*	*0.89*	*0.03*	*0.00*	*0.04*	*0.01*	*0.02*	*2.00*
24	40 gr30	sk1+sk2	59.0	2.3	0.0	33.2	0.6	0.0	0.9	0.0	0.0	99.2	*0.99*	*0.02*	*0.00*	*0.93*	*0.02*	*0.00*	*0.01*	*0.00*	*0.03*	*2.00*
25	40 gr30	sk1+sk2	57.0	2.6	1.9	27.5	0.8	0.0	5.1	0.0	4.7	99.6	*1.00*	*0.02*	*0.02*	*0.81*	*0.03*	*0.00*	*0.08*	*0.00*	*0.04*	*2.00*
26	40 gr32	sk	53.1	2.5	7.7	31.5	3.3	0.0	0.0	1.3	0.0	99.4	*0.89*	*0.02*	*0.07*	*0.89*	*0.11*	*0.00*	*0.00*	*0.03*	*0.00*	*2.00*
27	40 gr33	sk	59.5	4.9	0.0	30.0	5.6	0.0	0.0	0.0	0.0	100.0	*0.97*	*0.04*	*0.00*	*0.82*	*0.17*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
28	40 gr34	sk	57.7	3.3	0.0	34.8	4.0	0.0	0.0	0.0	0.0	99.9	*0.92*	*0.03*	*0.00*	*0.93*	*0.12*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
29	40 gr35	sk	57.4	1.2	4.6	30.5	3.1	0.5	0.0	1.8	0.0	99,1`	*0.96*	*0.01*	*0.04*	*0.85*	*0.10*	*0.01*	*0.00*	*0.02*	*0.00*	*2.00*
30	40 gr36	sk+bn+ch	61.2	1.9	0.0	29.2	6.7	0.6	0.0	0.0	0.0	99.6	*0.98*	*0.02*	*0.00*	*0.78*	*0.20*	*0.02*	*0.00*	*0.00*	*0.00*	*2.00*
31	40 gr37	sk+bn	58.1	2.8	1.0	30.8	2.6	1.0	3.4	0.0	0.0	99.7	*0.96*	*0.03*	*0.01*	*0.85*	*0.08*	*0.03*	*0.05*	*0.00*	*0.00*	*2.00*
32	40 gr38	sk+bn	49.5	1.3	12.4	31.4	2.4	0.0	0.0	1.9	1.0	99.9	*0.85*	*0.01*	*0.12*	*0.90*	*0.08*	*0.00*	*0.00*	*0.03*	*0.01*	*2.00*
33	40 gr39	sk	61.9	0.0	0.9	31.2	3.1	2.2	0.0	0.0	0.0	99.3	*1.00*	*0.00*	*0.01*	*0.84*	*0.10*	*0.06*	*0.00*	*0.00*	*0.00*	*2.00*
34	40 gr41	sk	50.8	12.6	1.5	27.3	6.3	0.0	0.0	0.9	0.0	99.4	*0.87*	*0.12*	*0.01*	*0.78*	*0.20*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*

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

Table 6 24-1059 continued

			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***
35	40 gr42	sk	59.7	3.7	0.0	30.3	5.3	0.0	0.0	0.0	1.0	100.0	*0.97*	*0.03*	*0.00*	*0.82*	*0.16*	*0.00*	*0.00*	*0.00*	*0.01*	*2.00*
36	40 gr43	sk+ch+bn	54.7	7.5	0.9	26.5	6.9	1.2	0.0	0.0	1.6	99.3	*0.91*	*0.07*	*0.01*	*0.74*	*0.22*	*0.03*	*0.00*	*0.00*	*0.01*	*2.00*
37	40 gr45	sk+bn+ch	60.5	0.0	1.7	29.6	4.2	2.4	0.0	0.7	0.0	99.1	*0.98*	*0.00*	*0.02*	*0.80*	*0.13*	*0.06*	*0.00*	*0.01*	*0.00*	*2.00*
38	40 gr46	sk+bn	59.1	0.0	0.0	35.2	3.4	1.2	0.0	0.0	0.0	98.9	*0.93*	*0.00*	*0.00*	*0.93*	*0.10*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
39	40 gr48	sk	58.3	0.9	1.9	33.3	4.0	0.0	0.0	1.1	0.0	99.5	*0.94*	*0.01*	*0.02*	*0.90*	*0.12*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*
40	40 gr49	sk	58.0	1.6	2.7	30.5	5.2	0.0	0.0	1.1	0.0	99.1	*0.95*	*0.01*	*0.02*	*0.84*	*0.16*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*
41	40 gr51	sk+(Pd,Cu,Sn)+bn	57.7	2.0	2.2	24.0	0.6	0.0	9.2	0.8	3.6	99.1	*1.03*	*0.02*	*0.02*	*0.72*	*0.02*	*0.00*	*0.15*	*0.01*	*0.03*	*2.00*
42	40 gr52	sk+bn	57.3	4.3	0.0	30.5	5.4	0.9	0.0	0.0	1.0	99.4	*0.93*	*0.04*	*0.00*	*0.83*	*0.17*	*0.02*	*0.00*	*0.00*	*0.01*	*2.00*
43	40 gr 53	sk	56.4	1.2	4.7	31.2	5.1	0.0	0.0	1.4	0	100.0	*0.92*	*0.01*	*0.04*	*0.85*	*0.16*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
44	40 gr54	sk+bn+ch	44.9	8.9	7.3	32.1	3.8	0.7	0.0	1.8	0.0	99.5	*0.77*	*0.08*	*0.07*	*0.92*	*0.12*	*0.02*	*0.00*	*0.03*	*0.00*	*2.00*
45	40 gr55	sk+bn	58.5	1.1	2.3	29.9	3.0	1.6	0.0	0.0	2.7	99.3	*0.97*	*0.01*	*0.02*	*0.83*	*0.10*	*0.04*	*0.00*	*0.00*	*0.02*	*2.00*
46	40 gr56	sk+bn+ch	60.6	2.4	0.0	28.7	7.0	1.3	0.0	0.0	0.0	100.0	*0.97*	*0.02*	*0.00*	*0.77*	*0.21*	*0.03*	*0.00*	*0.00*	*0.00*	*2.00*
47	40 gr57	sk+ch	55.2	0.0	8.3	31.7	1.7	1.8	0.0	0.0	0.0	99.3	*0.92*	*0.00*	*0.08*	*0.89*	*0.05*	*0.05*	*0.00*	*0.01*	*0.00*	*2.00*
48	40 gr59	sk	60.9	0	0.0	33.6	5.2	0.0	0.0	0.0	0.0	99.7	*0.96*	*0.00*	*0.00*	*0.88*	*0.16*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
49	40 gr60	sk+bn	58.3	0.0	3.4	32.9	2.6	2.1	0.0	0.0	0.0	99.4	*0.94*	*0.00*	*0.03*	*0.89*	*0.08*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
50	40 gr61	sk	57.7	1.0	3.3	32.5	2.9	0.0	0.0	0.9	1.6	99.9	*0.95*	*0.01*	*0.03*	*0.90*	*0.09*	*0.00*	*0.00*	*0.01*	*0.01*	*2.00*
51	40 gr62	sk+ch+bn	62.2	0.0	0.0	29.6	4.4	3.0	0.0	0.0	0.0	99.2	*0.99*	*0.00*	*0.00*	*0.79*	*0.14*	*0.08*	*0.00*	*0.00*	*0.00*	*2.00*
52	40 gr63	sk	48.6	1.6	12.4	34.0	2.0	0.0	0.0	0.7	0.0	99.3	*0.90*	*0.02*	*0.12*	*0.88*	*0.07*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*
53	40 gr64	sk+vs	43.6	3.6	15.1	32.8	1.8	0.0	0.0	0.0	2.4	99.3	*0.77*	*0.03*	*0.14*	*0.97*	*0.06*	*0.00*	*0.00*	*0.00*	*0.02*	*2.00*
54	40 gr65	sk+ch	55.7	5.9	0.0	33.5	2.2	1.9	0.0	0.0	1.7	100.9	*0.90*	*0.05*	*0.00*	*0.91*	*0.07*	*0.05*	*0.00*	*0.00*	*0.01*	*2.00*
55	40 gr66	sk+ch+bn	59.8	0.0	0.0	32.4	1.8	1.5	1.8	0.0	1.9	99.2	*0.98*	*0.00*	*0.00*	*0.89*	*0.06*	*0.04*	*0.03*	*0.00*	*0.02*	*2.00*
56	40 gr67	sk	55.0	4.8	2.9	29.8	5.2	0.0	0.0	1.3	1.1	100.1	*0.91*	*0.04*	*0.03*	*0.83*	*0.16*	*0.00*	*0.00*	*0.02*	*0.01*	*2.00*
57	40 gr68	sk	56.9	1.2	5.8	31.0	2.8	0.0	0.0	1.6	0.0	99.3	*0.95*	*0.01*	*0.05*	*0.87*	*0.09*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
58	40 gr69	sk	60.8	0.0	0.0	31.8	5.4	0.9	0.0	0.0	0.0	98.9	*0.97*	*0.00*	*0.00*	*0.85*	*0.16*	*0.02*	*0.00*	*0.00*	*0.00*	*2.00*
59	40 gr70	sk+bn+ch	56.8	0.0	3.1	35.2	2.6	1.7	0.0	0.0	0.0	99.4	*0.97*	*0.00*	*0.03*	*0.87*	*0.08*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
60	40 gr71	sk	60.4	0.0	3.1	29.4	4.9	0.0	0.0	1.2	0.0	99.0	*1.00*	*0.00*	*0.03*	*0.81*	*0.15*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
61	40 gr72	sk	56.7	1.5	5.1	30.8	3.6	0.0	0.0	1.4	0.0	99.1	*0.95*	*0.01*	*0.05*	*0.86*	*0.12*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
62	40 gr77	sk	58.2	3.5	0.0	30.2	3.9	0.7	0.0	2.5	0.0	99.0	*0.96*	*0.03*	*0.00*	*0.84*	*0.12*	*0.02*	*0.00*	*0.03*	*0.00*	*2.00*
63	40 gr78	sk	61.5	0.0	1.9	31.0	4.8	0.5	0.0	0.7	0.0	100.5	*0.98*	*0.00*	*0.02*	*0.83*	*0.15*	*0.01*	*0.00*	*0.01*	*0.00*	*2.00*
64	40 gr79	sk+ch+ilm	61.5	1.2	0.0	31.9	1.3	1.3	2.8	0.0	0.0	100.1	*0.99*	*0.01*	*0.00*	*0.88*	*0.04*	*0.03*	*0.04*	*0.00*	*0.00*	*2.00*
65	40 gr80	sk+ch	60.7	0.0	1.5	35.2	1.8	1.5	0.0	0.0	0.0	100.8	*0.96*	*0.00*	*0.01*	*0.93*	*0.06*	*0.04*	*0.00*	*0.00*	*0.00*	*2.00*
66	40 gr81	sk+bn+ch	61.5	0.0	0.0	32.2	5.0	1.4	0.0	0.0	0.0	100.1	*0.97*	*0.00*	*0.00*	*0.85*	*0.15*	*0.04*	*0.00*	*0.00*	*0.00*	*2.00*
67	40 gr82	sk+ch	50.8	8.9	1.5	33.0	4.8	0.0	0.0	1.0	0.0	100.0	*0.83*	*0.08*	*0.01*	*0.81*	*0.15*	*0.00*	*0.00*	*0.01*	*0.00*	*2.00*
68	40 gr83	sk+bn	62.8	0.0	0.0	28.1	7.0	0.0	0.0	0.0	0.0	99.1	*1.01*	*0.00*	*0.00*	*0.76*	*0.21*	*0.00*	*0.00*	*0.00*	*0.01*	*2.00*
69	40 gr84	sk+bn+ch	59.7	0.0	0.0	27.6	0.6	0.0	10.5	0.0	1.4	99.8	*1.01*	*0.00*	*0.00*	*0.80*	*0.02*	*0.00*	*0.16*	*0.00*	*0.01*	*2.00*
70	63 gr3	sk+bn+ch	58.8	2.8	0.0	33.9	5.1	0.0	0.0	0.0	0.0	100.5	*0.94*	*0.02*	*0.00*	*0.88*	*0.15*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
71	63 gr4	sk+bn+ch	63.4	0.0	0.0	29.5	6.3	0.0	0.0	0.0	0.0	99.2	*1.02*	*0.00*	*0.00*	*0.79*	*0.19*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*

Abbreviations: sk: skaergaardite; (Pd,Cu,Sn): alloy; vs: vasilitebn: bornite: ch:chalcosine;ilm: ilmenite.

Table 6 24-1059 continued

			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***
72	63 gr6	sk	56.4	0.0	6.7	31.6	3.5	0.6	0.0	1.3	0.0	100.2	*0.93*	*0.00*	*0.06*	*0.87*	*0.11*	*0.02*	*0.00*	*0.02*	*0.00*	*2.00*
73	63 gr7	sk+bn+ch	62.4	0.0	0.0	28.9	4.8	1.6	0.8	0.0	1.1	99.6	*1.01*	*0.00*	*0.00*	*0.78*	*0.15*	*0.04*	*0.01*	*0.00*	*0.01*	*2.00*
74	63 gr8	sk	63.7	0.0	0.0	29.7	5.4	1.8	0.0	0.0	0.0	100.6	*1.01*	*0.00*	*0.00*	*0.79*	*0.15*	*0.05*	*0.00*	*0.00*	*0.00*	*2.00*
75	63 gr10	sk+bn+ch	59.8	0.0	2.2	33.1	1.0	0.7	2.1	0.0	0.9	99.8	*0.98*	*0.00*	*0.02*	*0.91*	*0.03*	*0.02*	*0.03*	*0.00*	*0.01*	*2.00*
76	63 gr11	sk+bn+ch	61.6	0.0	0.0	30.7	2.4	1.7	0.9	0.7	1.2	99.2	*1.01*	*0.00*	*0.00*	*0.84*	*0.07*	*0.05*	*0.01*	*0.01*	*0.01*	*2.00*
77	63 gr12	sk+bn+ch	55.7	7.1	0.0	29.2	5.4	0.8	0.0	0.0	1.1	99.4	*0.92*	*0.06*	*0.00*	*0.81*	*0.17*	*0.02*	*0.00*	*0.00*	*0.01*	*2.00*
78	63 gr13	sk+bn+ch	59.2	3.1	0.0	29.7	4.7	0.7	0.0	0.0	1.7	99.1	*0.97*	*0.03*	*0.00*	*0.82*	*0.15*	*0.02*	*0.00*	*0.00*	*0.01*	*2.00*
79	63 gr14	sk	59.0	0.0	4.1	30.6	3.9	0.0	0.0	1.5	0.0	99.1	*0.97*	*0.00*	*0.04*	*0.84*	*0.12*	*0.00*	*0.00*	*0.02*	*0.00*	*2.00*
80	80 gr2	sk+bn+ch	49.8	11.3	0.0	31.0	4.4	0.9	0.0	0.0	2.3	99.8	*0.84*	*0.10*	*0.00*	*0.87*	*0.14*	*0.03*	*0.00*	*0.00*	*0.02*	*2.00*
81	80 gr4	sk+ch+bn	55.8	3.0	1.9	29.1	1.0	6.4	0.0	0.0	2.3	99.5	*0.93*	*0.03*	*0.02*	*0.81*	*0.03*	*0.17*	*0.00*	*0.00*	*0.02*	*2.00*
82	80 gr5	sk+ch+bn	57.7	3.0	0.0	33.2	5.0	0.0	0.0	0.0	0.0	98.9	*0.93*	*0.03*	*0.00*	*0.89*	*0.15*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
83	80 gr7	sk+bn+ch	63.0	0.0	0.0	32.6	4.4	0.0	0.0	0.0	0.0	100.0	*1.00*	*0.00*	*0.00*	*0.87*	*0.13*	*0.00*	*0.00*	*0.00*	*0.00*	*2.00*
84	80 gr8	sk+bn+ch	62.7	0.0	0.0	31.6	4.8	1.6	0.0	0.0	0.0	100.7	*0.98*	*0.00*	*0.00*	*0.83*	*0.14*	*0.04*	*0.00*	*0.00*	*0.00*	*2.00*
85	80 gr9	sk+ch+bn	60.1	0.0	2.1	32.2	2.4	1.3	0.0	1.0	0.0	99.1	*0.98*	*0.00*	*0.02*	*0.88*	*0.08*	*0.03*	*0.00*	*0.01*	*0.00*	*2.00*
86	80 gr10	sk+ch+bn	60.6	0	1.6	33.8	1.5	2.1	0	0.9	0	100.6	*0.97*	*0.00*	*0.01*	*0.90*	*0.05*	*0.05*	*0.00*	*0.01*	*0.00*	*2.00*

Abbreviations: sk; skaergaardite; bn: bornite; chalcosine.

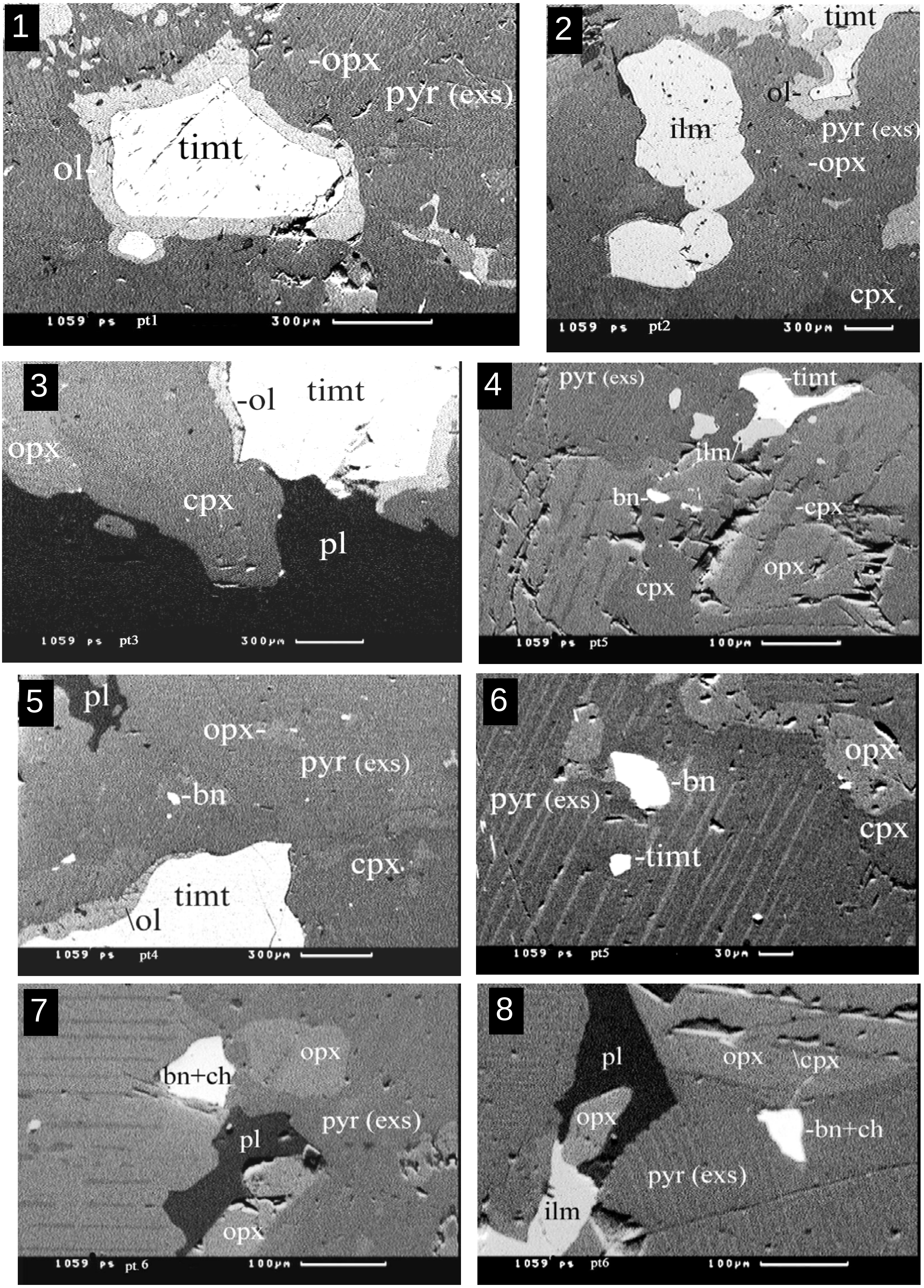
Table 7 Composition of (Cu,Pd) alloy, nielsenite and vasilite in PGM-grains in the heavy mineral concentrates of sample 90-24 1059

				Analysis (wt%)										*Proportions*									
An	**Grain**	**Association**	**Mineral**	**Pd**	**Pt**	**Au**	**Cu**	**Fe**	**Zn**	**Sn**	**Pb**	**S**	**Total**	***Pd***	***Pt***	***Au***	***Cu***	***Fe***	***Zn***	***Sn***	***Pb***	***S***	***Total***
1	40 gr58	nls+(Cu,Pd)+ch	(Cu,Pd)	53.40	1.6	3.1	35.30	2.8	2.2	0.0	1.0	-	99.40	*0.43*	*0.01*	*0.01*	*0.47*	*0.04*	*0.03*	*0.00*	*0.01*	-	*1.00*
2	40 gr58	nls+(Cu,Pd)+ch	nls	34.70	0.0	0.9	63.50	0.5	-	0.0	0.0	-	99.60	*0.97*	*0.00*	*0.01*	*2.99*	*0.03*	-	*0.00*	*0.00*	-	*4.00*
3	40 gr76	(Cu,Pd)+ilm	(Cu,Pd)	52.20	3.3	2.0	40.50	1.7	-	0.0	0.0	-	99.70	*0.41*	*0.01*	*0.01*	*0.54*	*0.03*	-	*0.00*	*0.00*	-	*1.00*
4	40 gr10	nls+ch	nls	35.80	0.0	0.0	62.70	1.3	-	0.0	0.0	-	99.80	*1.00*	*0.00*	*0.00*	*2.93*	*0.07*	-	*0.00*	*0.00*	-	*4.00*
5	40 gr51	sk+(Pd,Cu,Sn)+bn	(Pd,Cu,Sn)	61.50	0.0	1.8	15.60	0.6	-	16.7	3.0	-	99.20	*0.58*	*0.00*	*0.01*	*0.25*	*0.01*	-	*0.14*	*0.01*	-	*1.00*
6	40 gr64	vs+sk	vs	70.60	0.0	0.0	14.90	0.6	-	0.0	0.0	12.8	98.90	*11.65*	*0.00*	*0.00*	*4.13*	*0.19*	-	*0.00*	*0.00*	*7.03*	*23.00*

Abbreviations: nls: nielsenite; (Cu,Pd): alloy; Sk: skaergaardite; (Pd,Cu,Sn): alloy; vs: vasilite;ch: chalcosine

PLATES

Plate 1

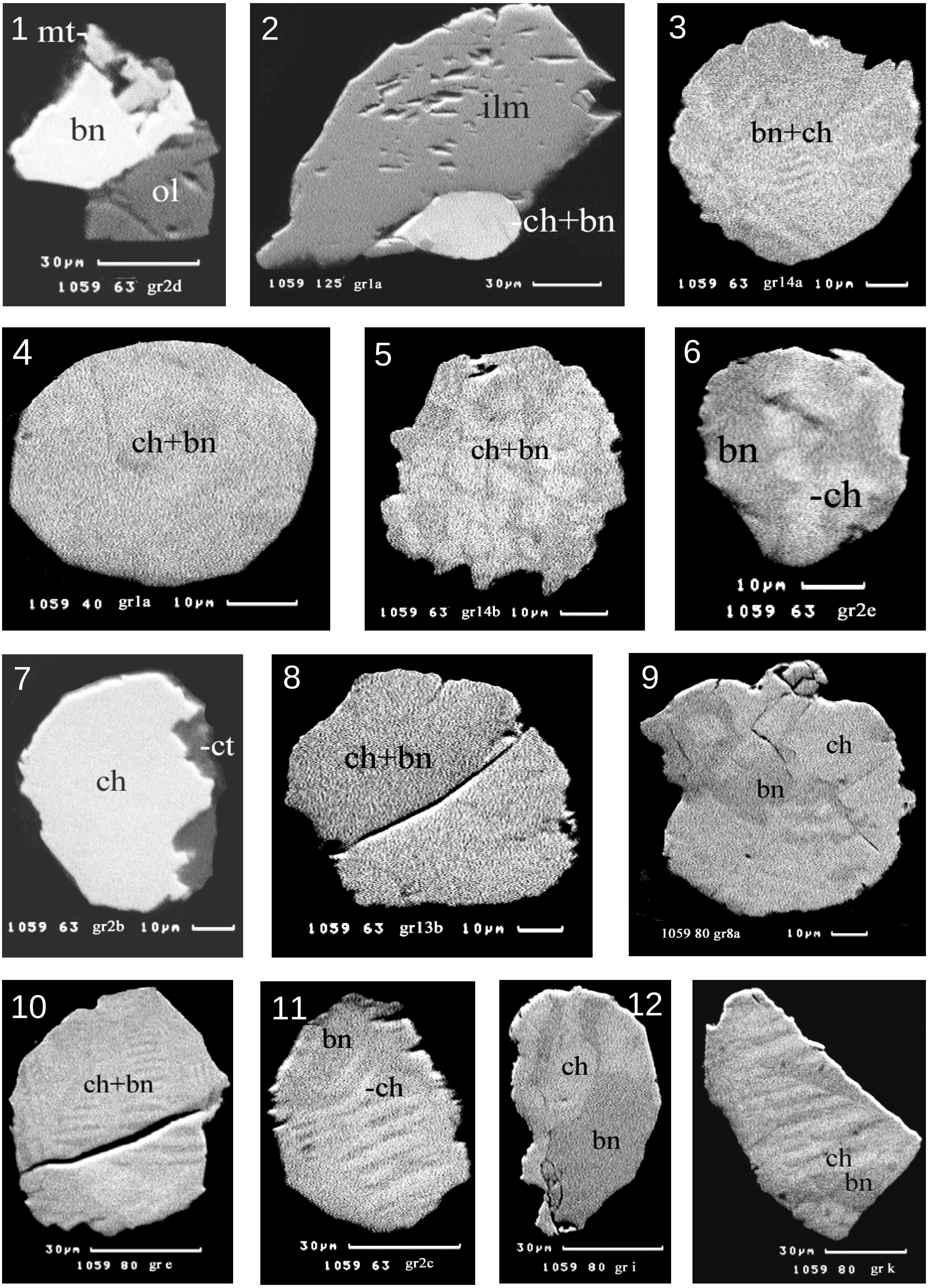


Relationships of rock-forming minerals, Fe-Ti oxides and sulphides in sample 90-24, 1059; polished section, SEM-image (BIE). Abbreviations:pl: plagioclase; pyr (exs): pyroxene with exsolution; cpx: clinopyroxene; opx: orthopyroxene; ol: olivine; ilm:ilmenite; timt: titanomagnetite; bn: bornite; ch:chalcosine

Plate 2

Sulphide globules in the heavy mineral concentrates of sample 90-24 1059, polished section, SEM-image (BIE).

Abbreviations: ol: olivine; mt: magnetite; ilm: ilmenite; ct: calcite; bn: bornite; ch; chalcosine and dg: digenite;



1 mt-
bn
ol
30μm
1059 63 gr2d
2
ilm
-ch+bn
1059 125 gr1a
30μm
3
bn+ch
1059 63 gr14a 10μm
4
ch+bn
1059 40 gr1a 10μm
5
ch+bn
1059 63 gr14b 10μm
6
bn
-ch
10μm
1059 63 gr2e
7
-ct
ch
1059 63 gr2b 10μm
8
ch+bn
1059 63 gr13b 10μm
9
ch
bn
1059 80 gr8a 10μm
10
ch+bn
30μm
1059 80 gre
11
bn
-ch
30μm
1059 63 gr2c
12
ch
bn
30μm
1059 80 gri
ch
bn
30μm
1059 80 grk

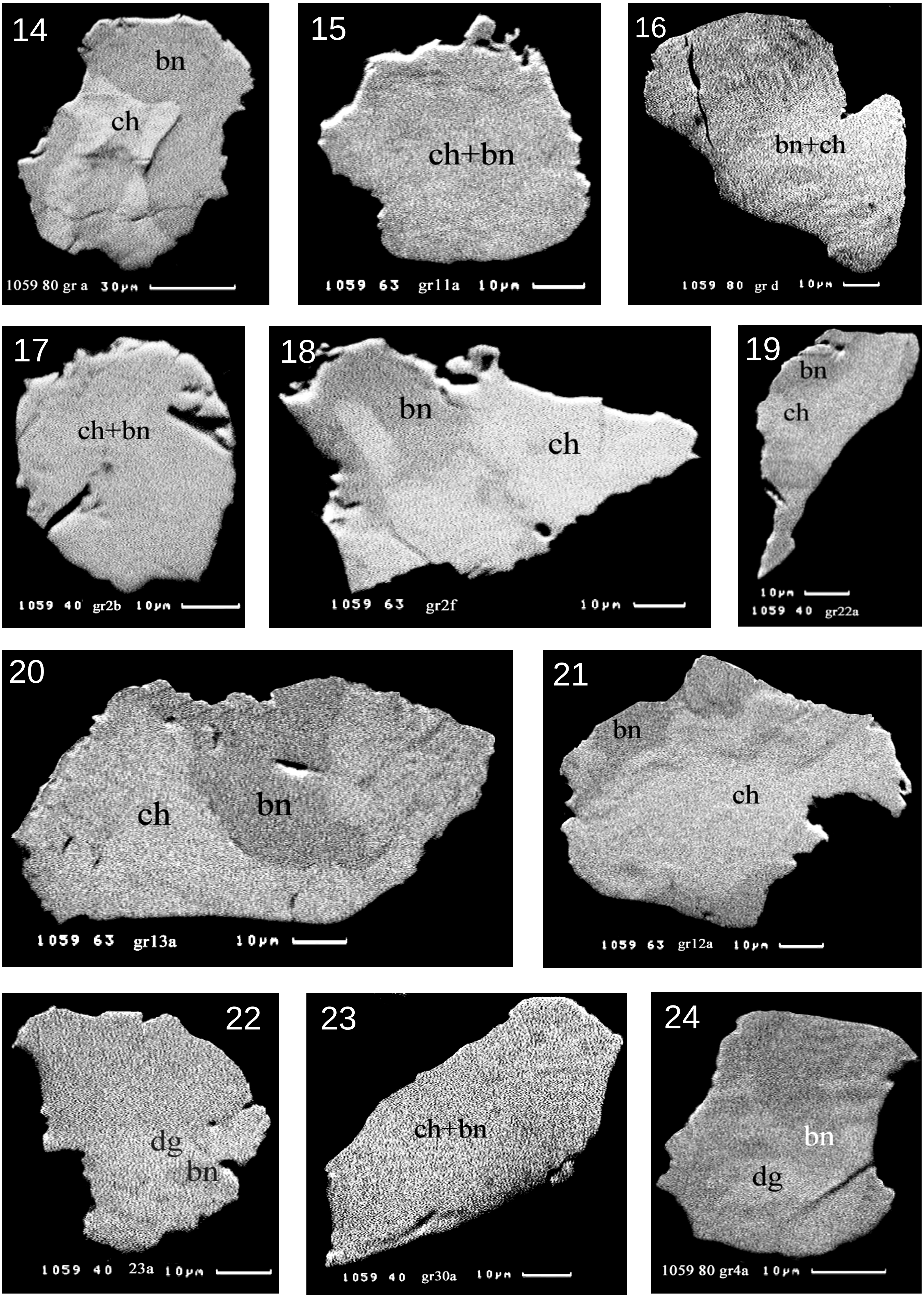
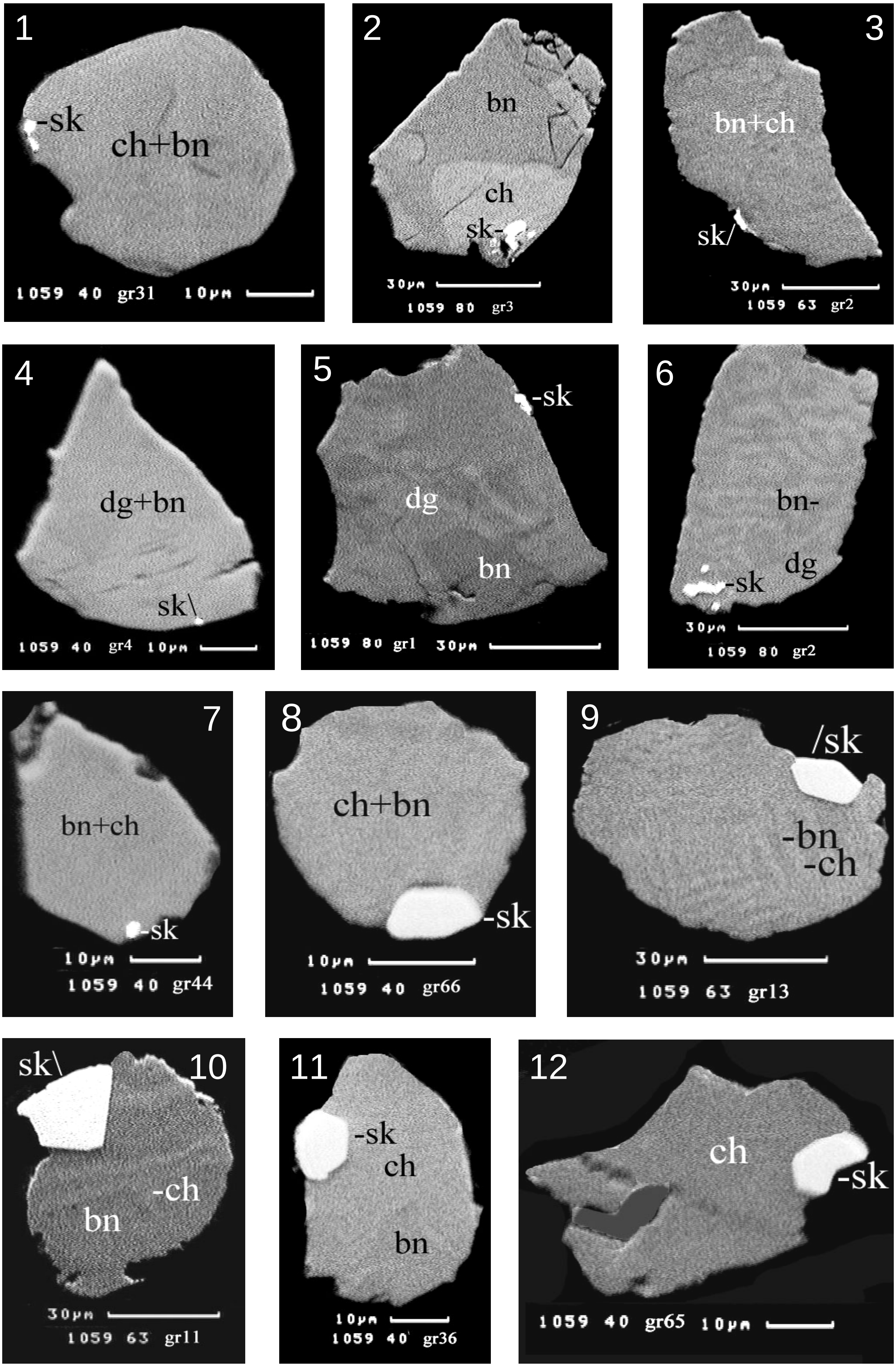
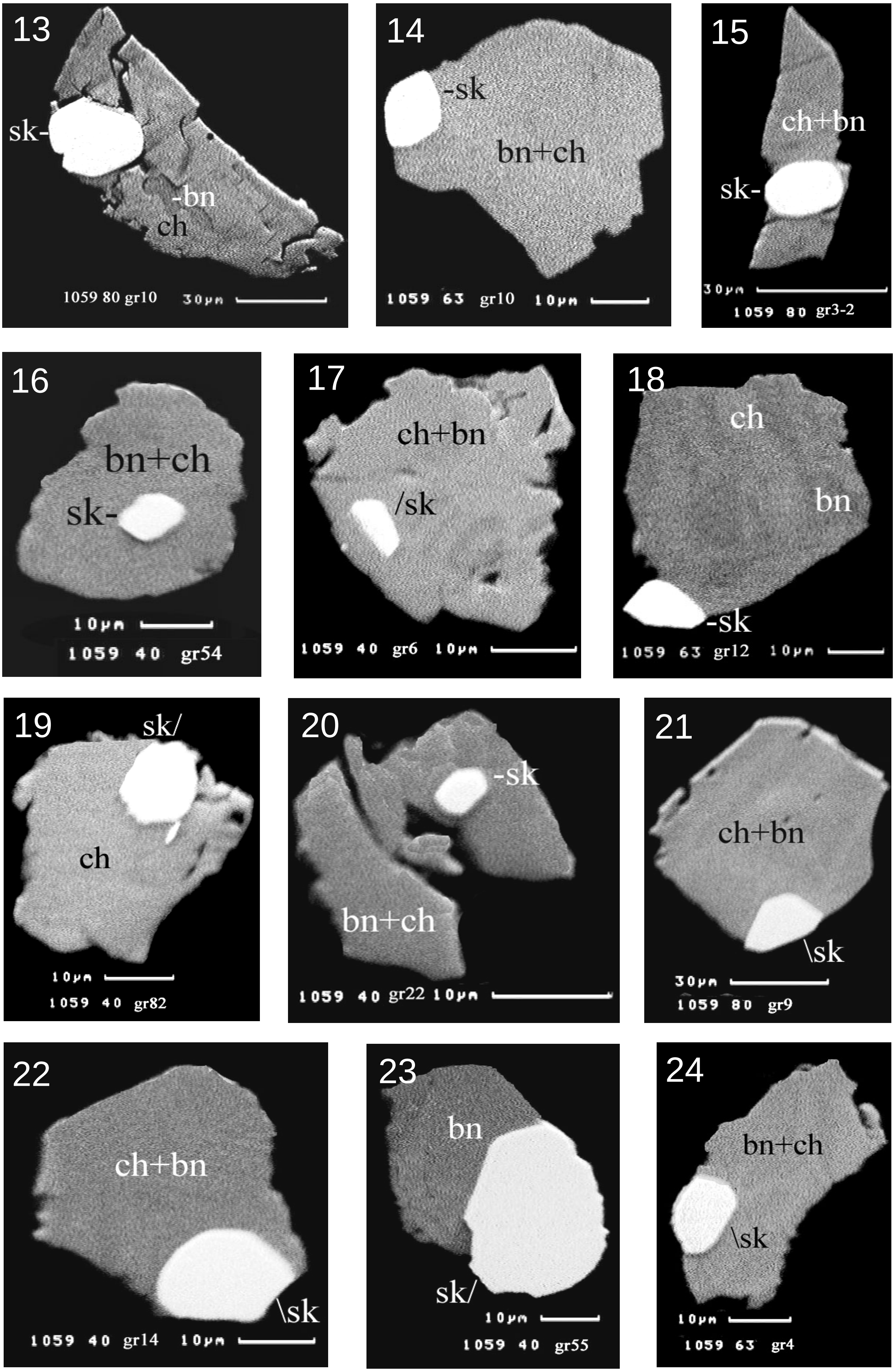

14
bn
ch
1059 80 gr a 30μm
15
ch+bn
1059 63 gr11a 10μm
16
bn+ch
1059 80 gr d 10μm
17
ch+bn
1059 40 gr2b 10μm
18
bn
ch
1059 63 gr2f 10μm
19
bn
ch
10μm
1059 40 gr22a
20
ch
bn
1059 63 gr13a 10μm
21
bn
ch
1059 63 gr12a 10μm
22
dg
bn
1059 40 23a 10μm
23
ch+bn
1059 40 gr30a 10μm
24
bn
dg
1059 80 gr4a 10μm

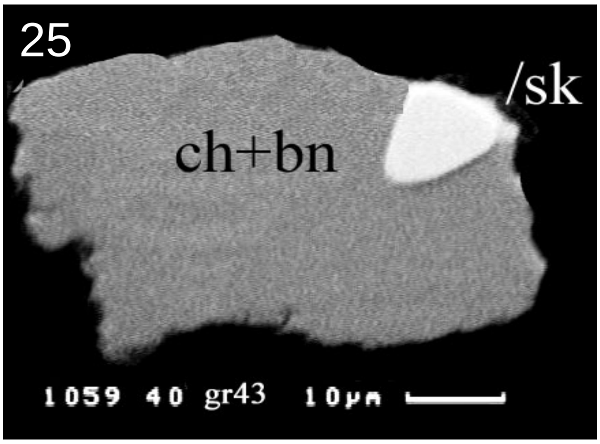
Plate 3

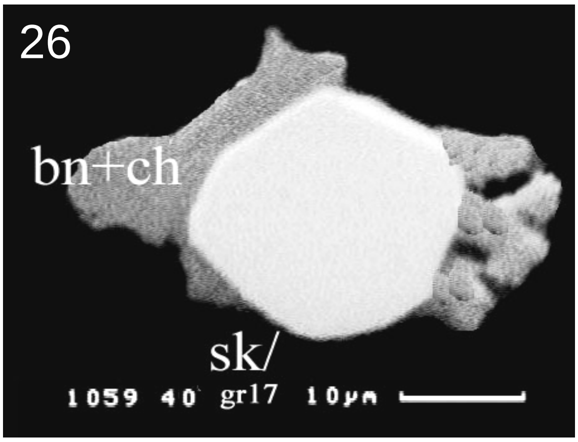
Sulphide globules with inclusions of skaergaardite (**bms**) and skaergaardite particles attached to base metal sulphides (**bms-L**)- in the heavy concentrates of sample 90-24 10 59; polished section, SEM-image (BIE).

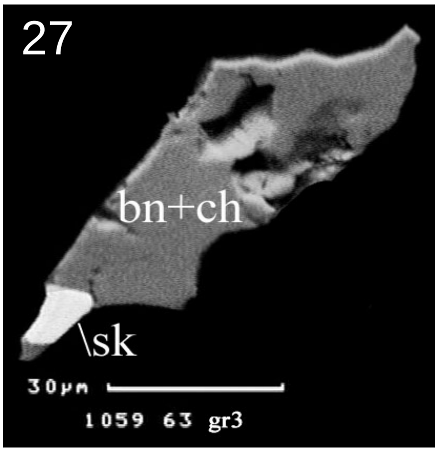
Abbreviations: sk: skaergaardite; bn: bornite; ch: chalcosine; dg: digenite.

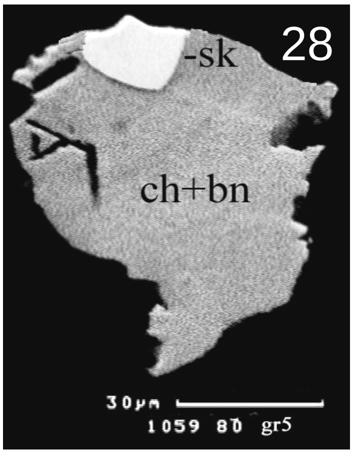

1
-sk
ch+bn
1059 40 gr31 10μm
2
bn
ch
sk-
30μm
1059 80 gr3
3
bn+ch
sk/
30μm
1059 63 gr2
4
dg+bn
sk\
1059 40 gr4 10μm
5
-sk
dg
bn
1059 80 gr1 30μm
6
bn-
dg
-sk
30μm
1059 80 gr2
7
bn+ch
-sk
10μm
1059 40 gr44
8
ch+bn
-sk
10μm
1059 40 gr66
9
/sk
-bn
-ch
30μm
1059 63 gr13
10
sk\
-ch
bn
30μm
1059 63 gr11
11
-sk
ch
bn
10μm
1059 40' gr36
12
ch
-sk
1059 40 gr65 10μm

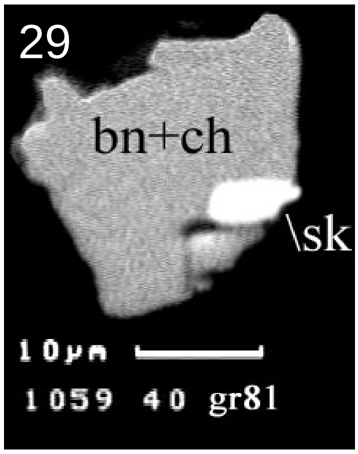

13
sk-
-bn
ch
1059 80 gr10
30μm
14
-sk
bn+ch
1059 63 gr10
10μm
15
ch+bn
sk-
30μm
1059 80 gr3-2
16
bn+ch
sk-
10μm
1059 40 gr54
17
ch+bn
/sk
1059 40 gr6
10μm
18
ch
bn
-sk
1059 63 gr12
10μm
19
sk/
ch
10μm
1059 40 gr82
20
-sk
bn+ch
1059 40 gr22
10μm
21
ch+bn
\sk
30μm
1059 80 gr9
22
ch+bn
\sk
1059 40 gr14
10μm
23
bn
sk/
10μm
1059 40 gr55
24
bn+ch
\sk
10μm
1059 63 gr4

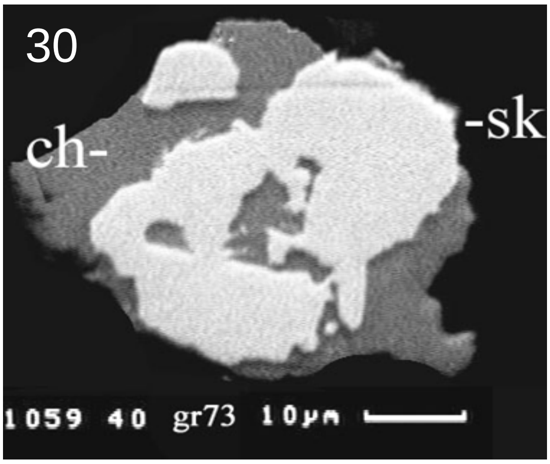

25
/sk
ch+bn
1059 40 gr43 10μm

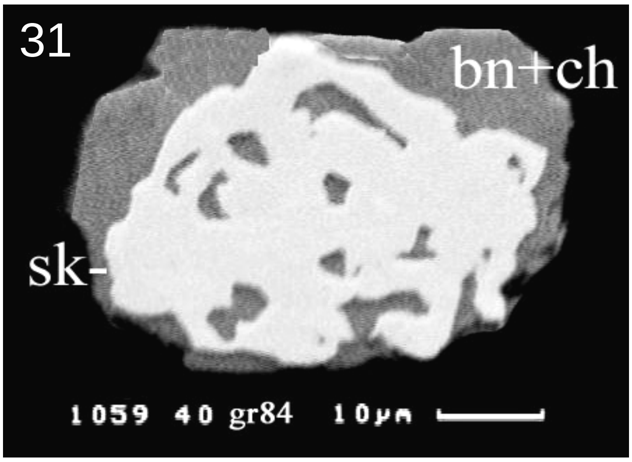

26
bn+ch
sk/
1059 40 gr17 10μm

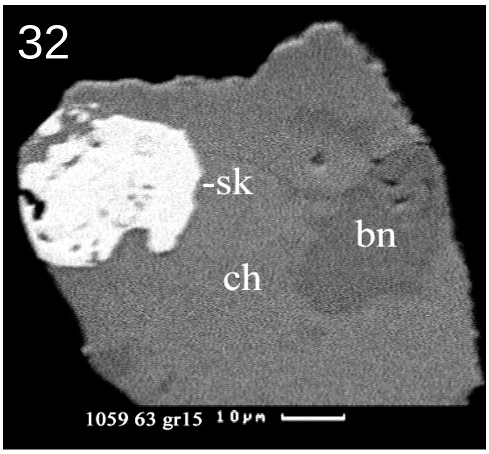

27
bn+ch
\sk
30μm
1059 63 gr3

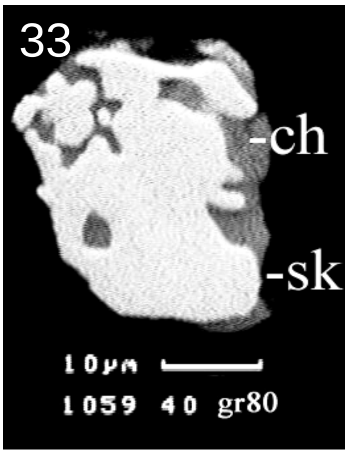

28
-sk
ch+bn
30μm
1059 80 gr5

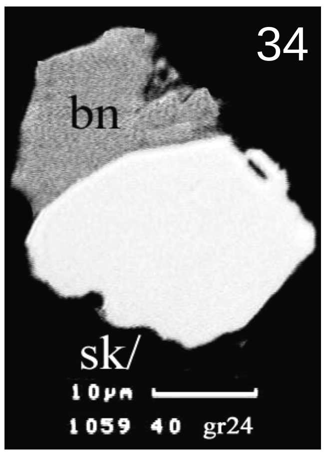

29
bn+ch
\sk
10μm
1059 40 gr81

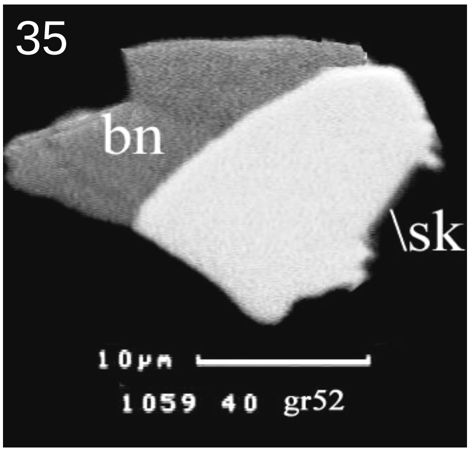

30
ch-
-sk
1059 40 gr73 10μm

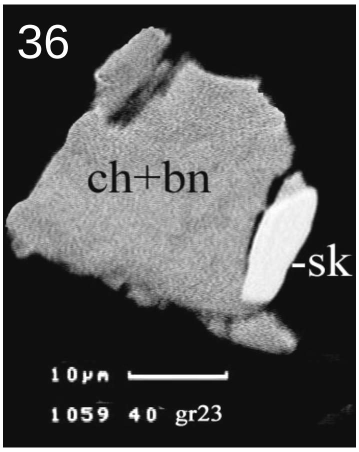

31
bn+ch
sk-
1059 40 gr84 10μm

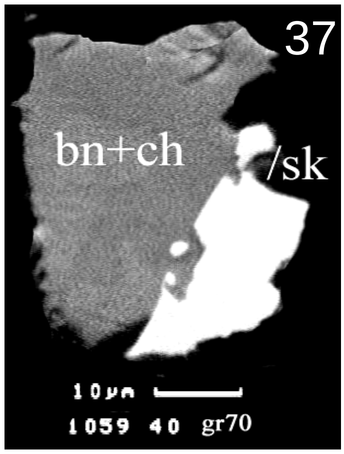

32
-sk
bn
ch
1059 63 gr15 10μm

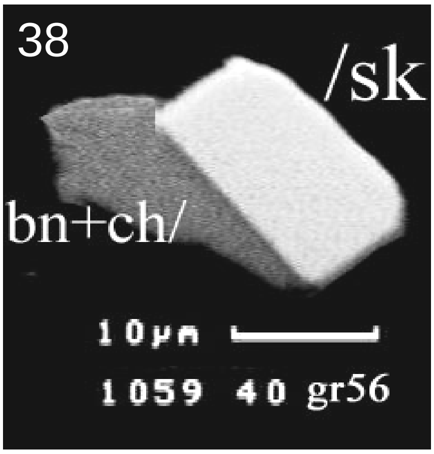

33
-ch
-sk
10μm
1059 40 gr80

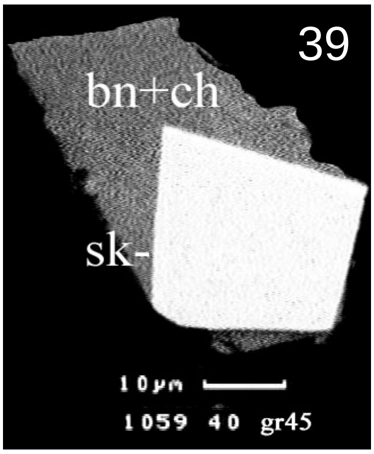

34
bn
sk/
10μm
1059 40 gr24

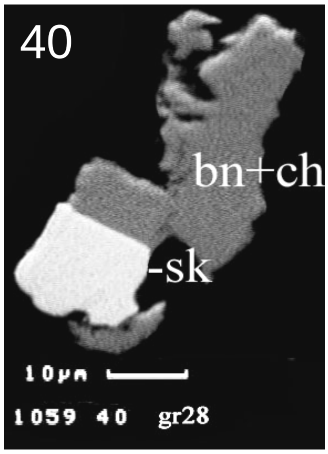

35
bn
\sk
10μm
1059 40 gr52

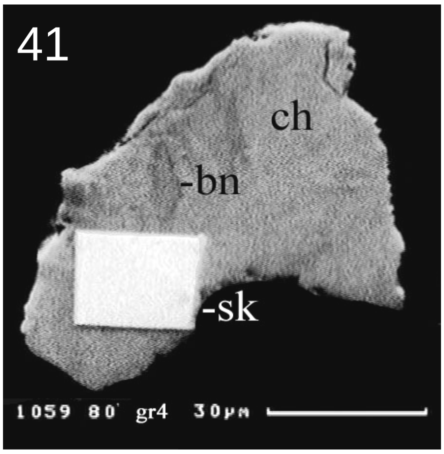

36
ch+bn
-sk
10μm
1059 40 gr23

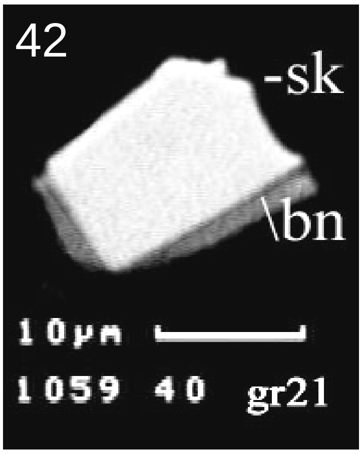

37
bn+ch
/sk
10μm
1059 40 gr70

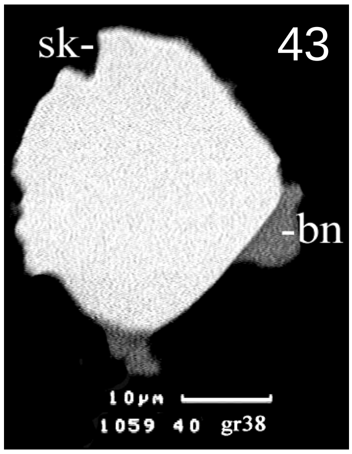

38
/sk
bn+ch/
10μm
1059 40 gr56

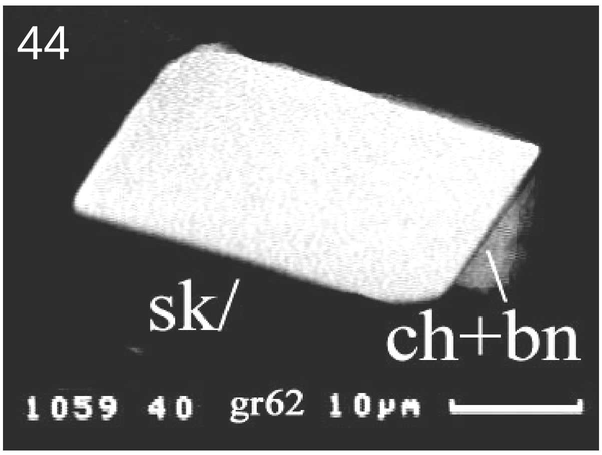

39
bn+ch
sk-
10μm
1059 40 gr45

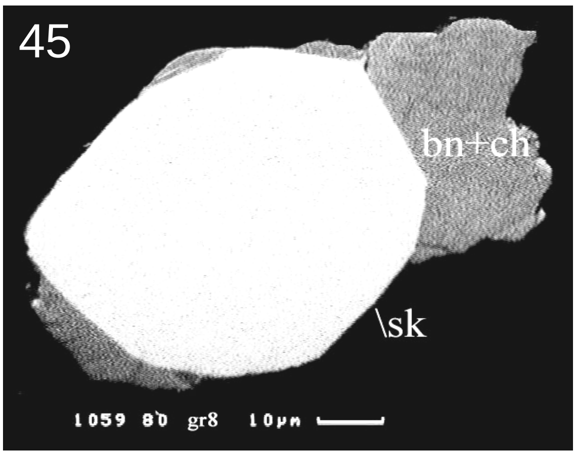

40
bn+ch
-sk
10μm
1059 40 gr28

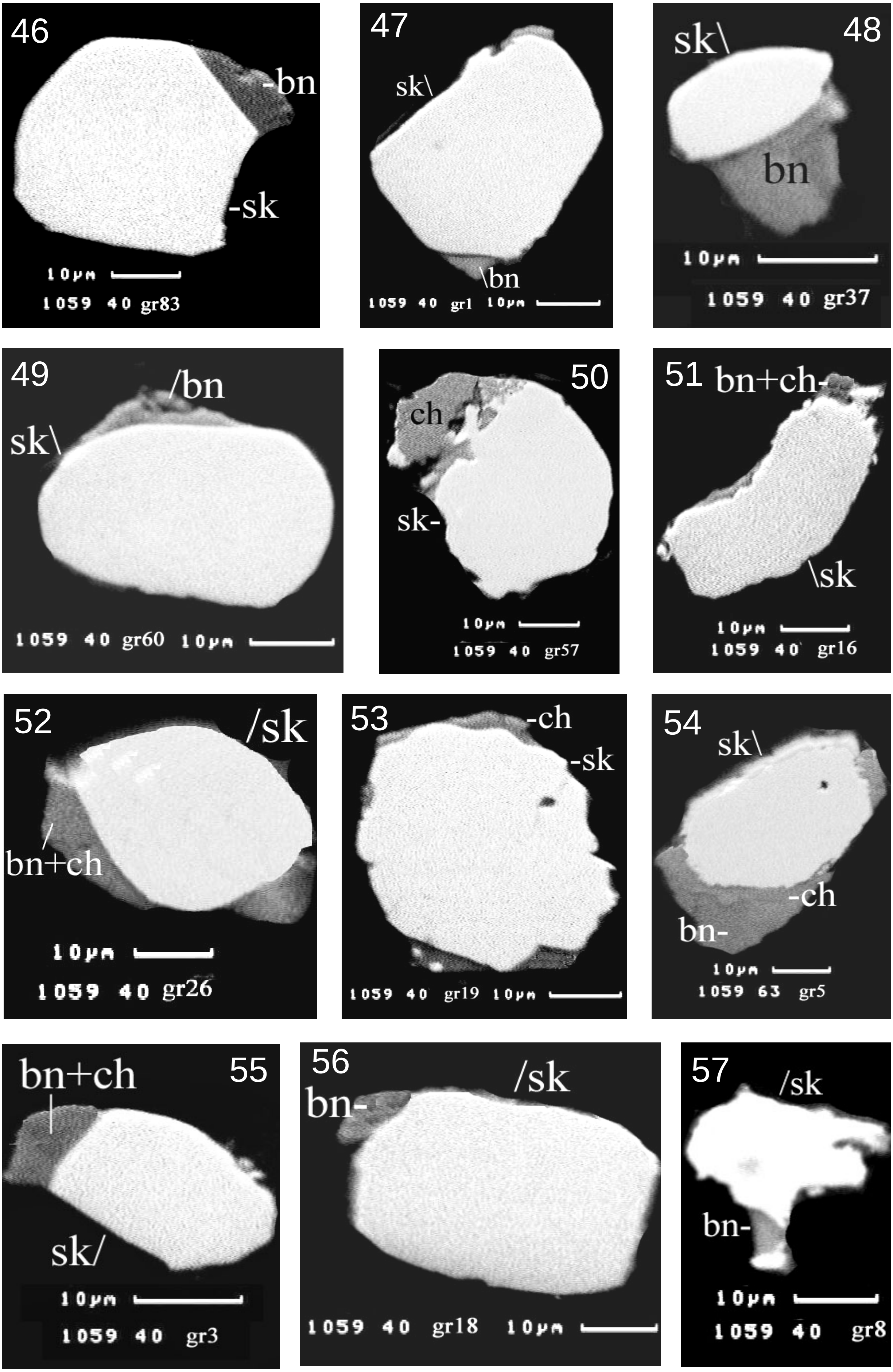

41
ch
-bn
-sk
1059 80 gr4 30μm


42
-sk
\bn
10μm
1059 40 gr21


sk-
43
-bn
10μm
1059 40 gr38


44
sk/
\
ch+bn
1059 40 gr62 10μm


45
bn+ch
\sk
1059 80 gr8 10μm


46
-bn
-sk
10μm
1059 40 gr83
47
sk\
\bn
1059 40 gr1 10μm
48
sk\
bn
10μm
1059 40 gr37
49
/bn
sk\
1059 40 gr60 10μm
50
ch
sk-
10μm
1059 40 gr57
51
bn+ch-
\sk
10μm
1059 40 gr16
52
/sk
bn+ch
10μm
1059 40 gr26
53
-ch
-sk
1059 40 gr19 10μm
54
sk\
-ch
bn-
10μm
1059 63 gr5
55
bn+ch
sk/
10μm
1059 40 gr3
56
bn-
/sk
1059 40 gr18 10μm
57
/sk
bn-
10μm
1059 40 gr8

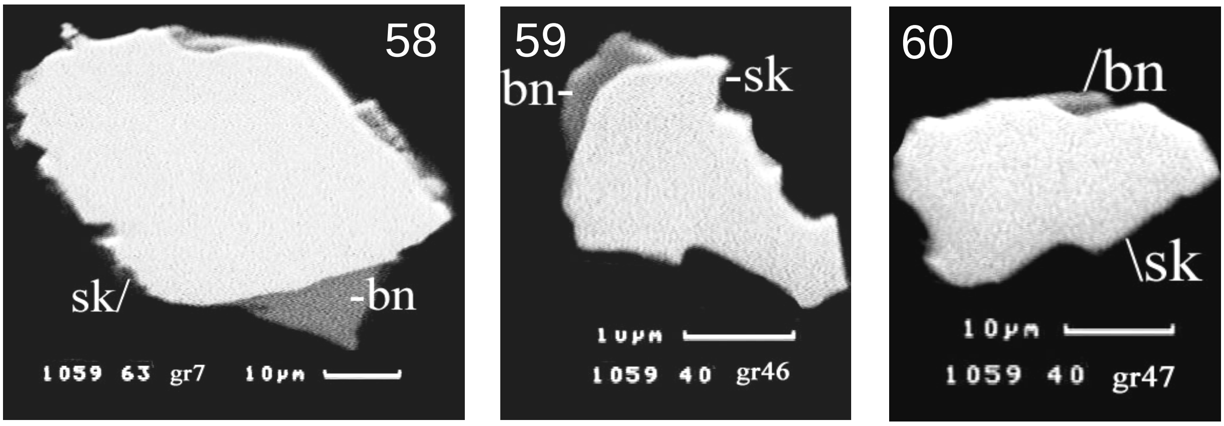
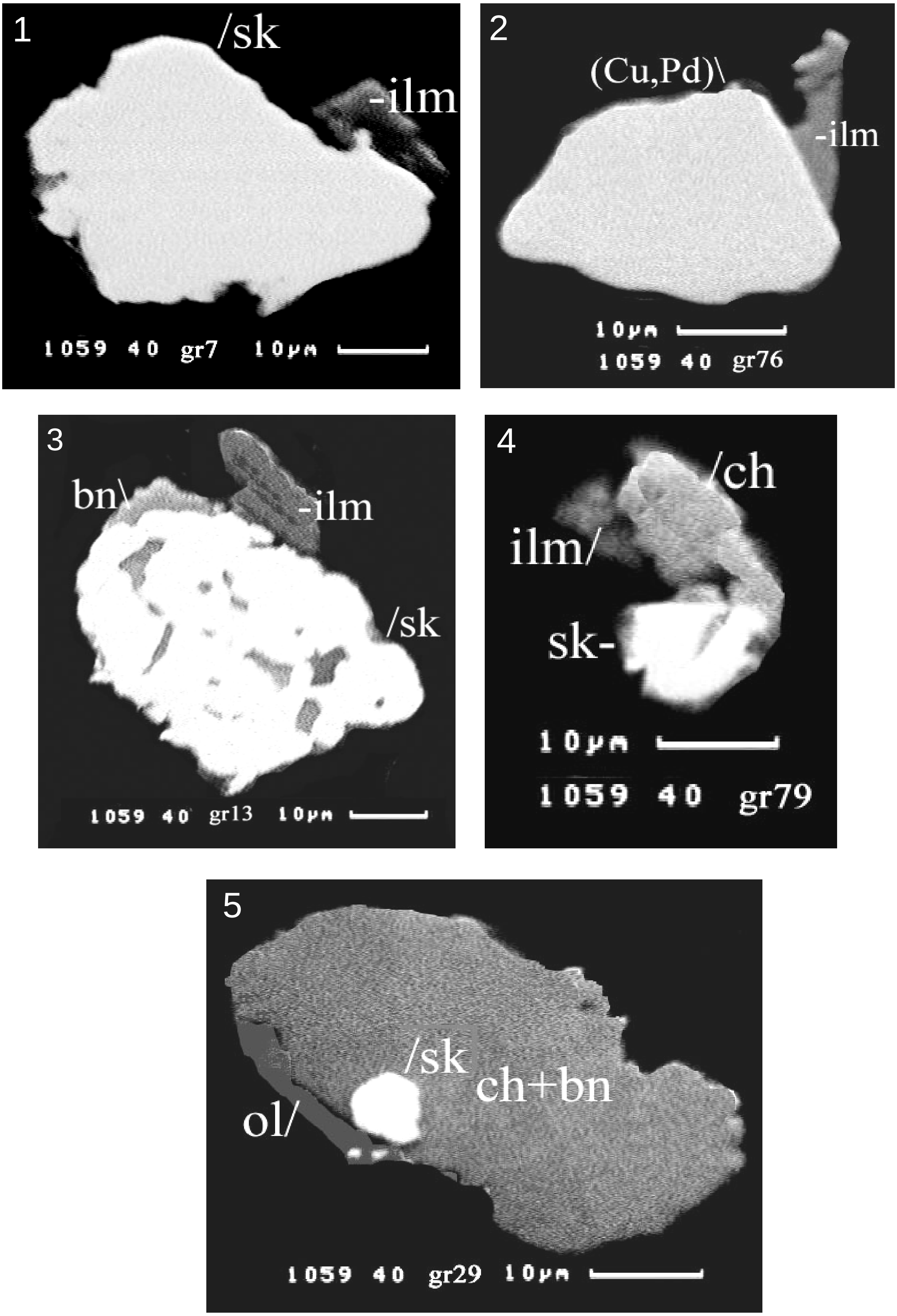

58
sk/
-bn
1059 63 gr7
10μm
59
bn-
-sk
10μm
1059 40 gr46
60
/bn
\sk
10μm
1059 40 gr47

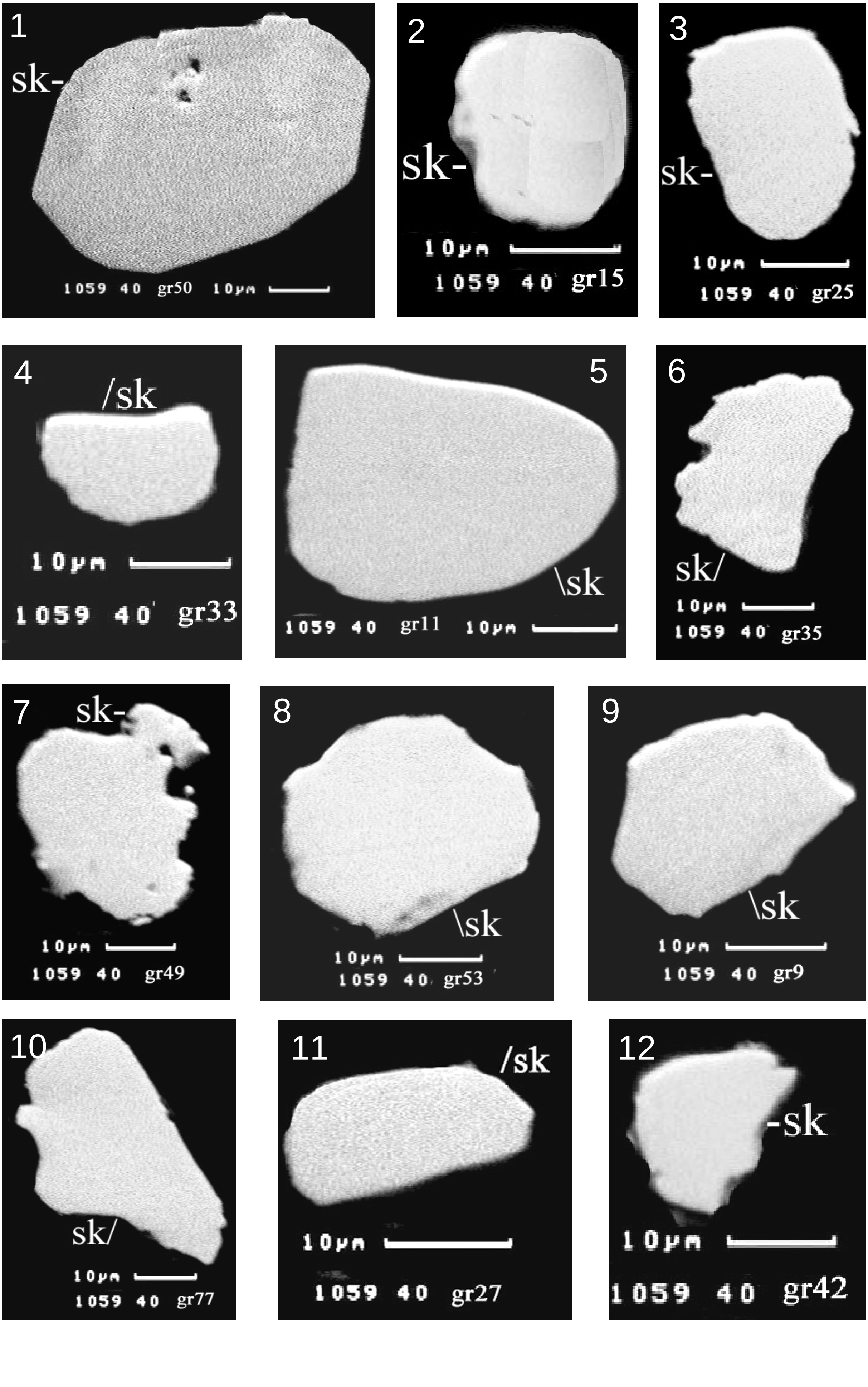
Plate 4

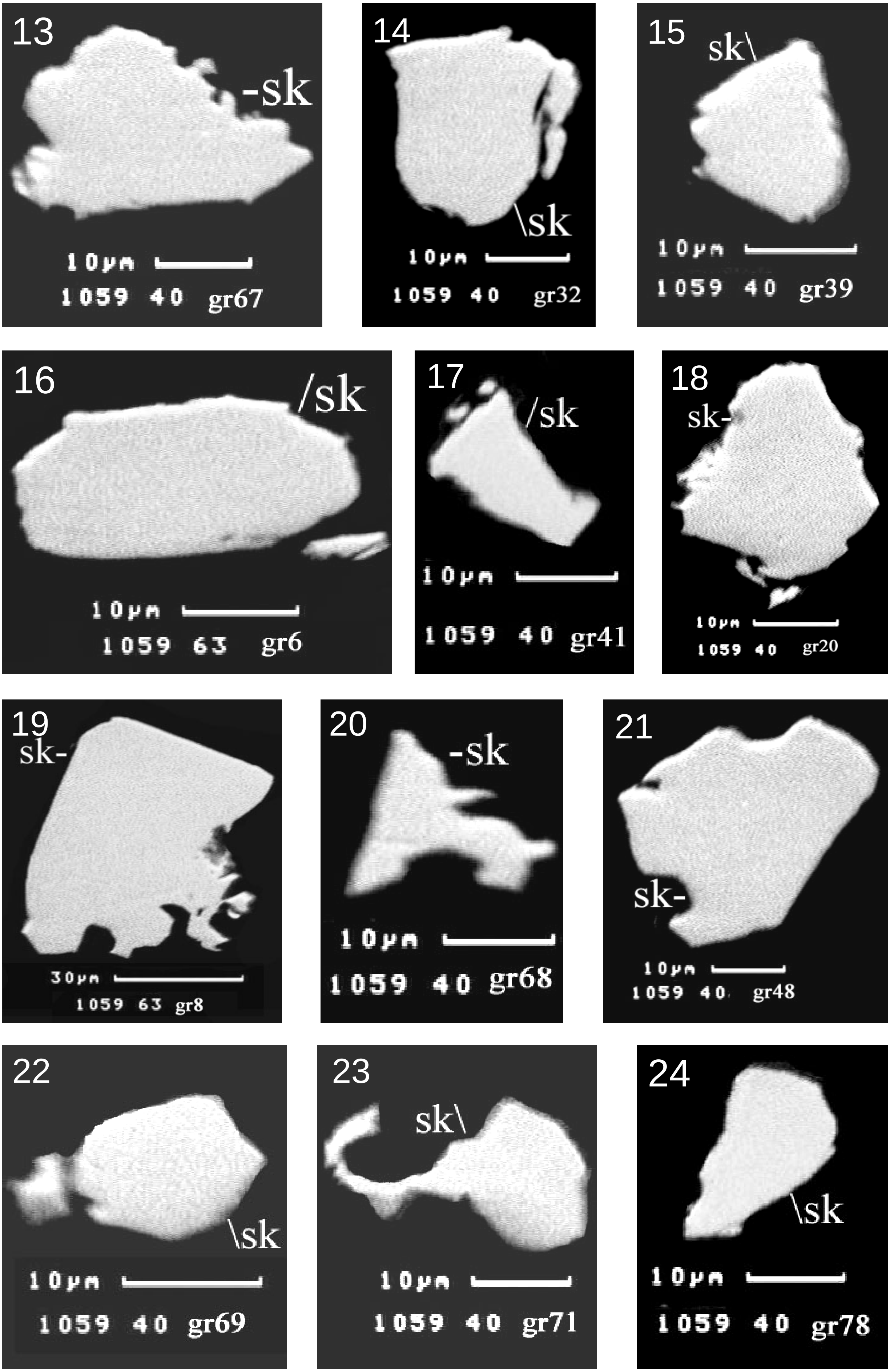


PGM grains attached to gangue or to gangue and sulphides in HS-concentrates of sample 90-24 1059; polished section, SEM-image (BIE). Abbreviations:SK: skaergaardite; ilm: ilmenite; (Cu,Pd): alloy; bn: bornite; ch: chalcosine; and ol: olivine.

Plate 5

Totally liberated grains of skaergaardite in The heavy mineral concentrates of sample 90-24 1056; polished section, SEM-images (BIE).


1
sk-
1059 40 gr50 10µm
2
sk-
10µm
1059 40 gr15
3
sk-
10µm
1059 40 gr25
4
/sk
10µm
1059 40 gr33
5
\sk
1059 40 gr11 10µm
6
sk/
10µm
1059 40 gr35
7
sk-
10µm
1059 40 gr49
8
\sk
10µm
1059 40 gr53
9
\sk
10µm
1059 40 gr9
10
sk/
10µm
1059 40 gr77
11
/sk
10µm
1059 40 gr27
12
-sk
10µm
1059 40 gr42


13
-sk
10μm
1059 40 gr67
14
\sk
10μm
1059 40 gr32
15
sk\
10μm
1059 40 gr39
16
/sk
10μm
1059 63 gr6
17
/sk
10μm
1059 40 gr41
18
sk-
10μm
1059 40 gr20
19
sk-
30μm
1059 63 gr8
20
-sk
10μm
1059 40 gr68
21
sk-
10μm
1059 40 gr48
22
\sk
10μm
1059 40 gr69
23
sk\
10μm
1059 40 gr71
24
\sk
10μm
1059 40 gr78

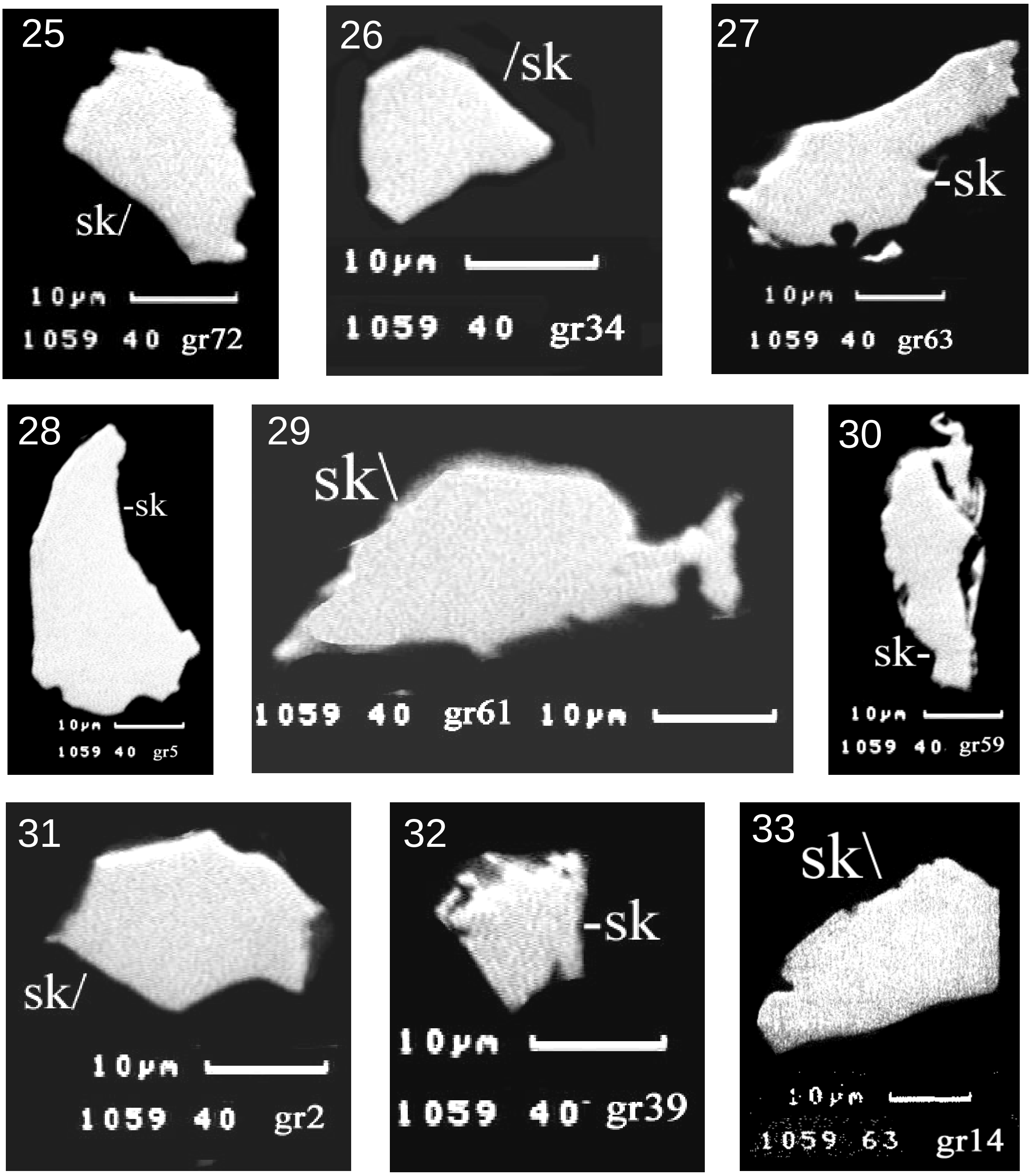
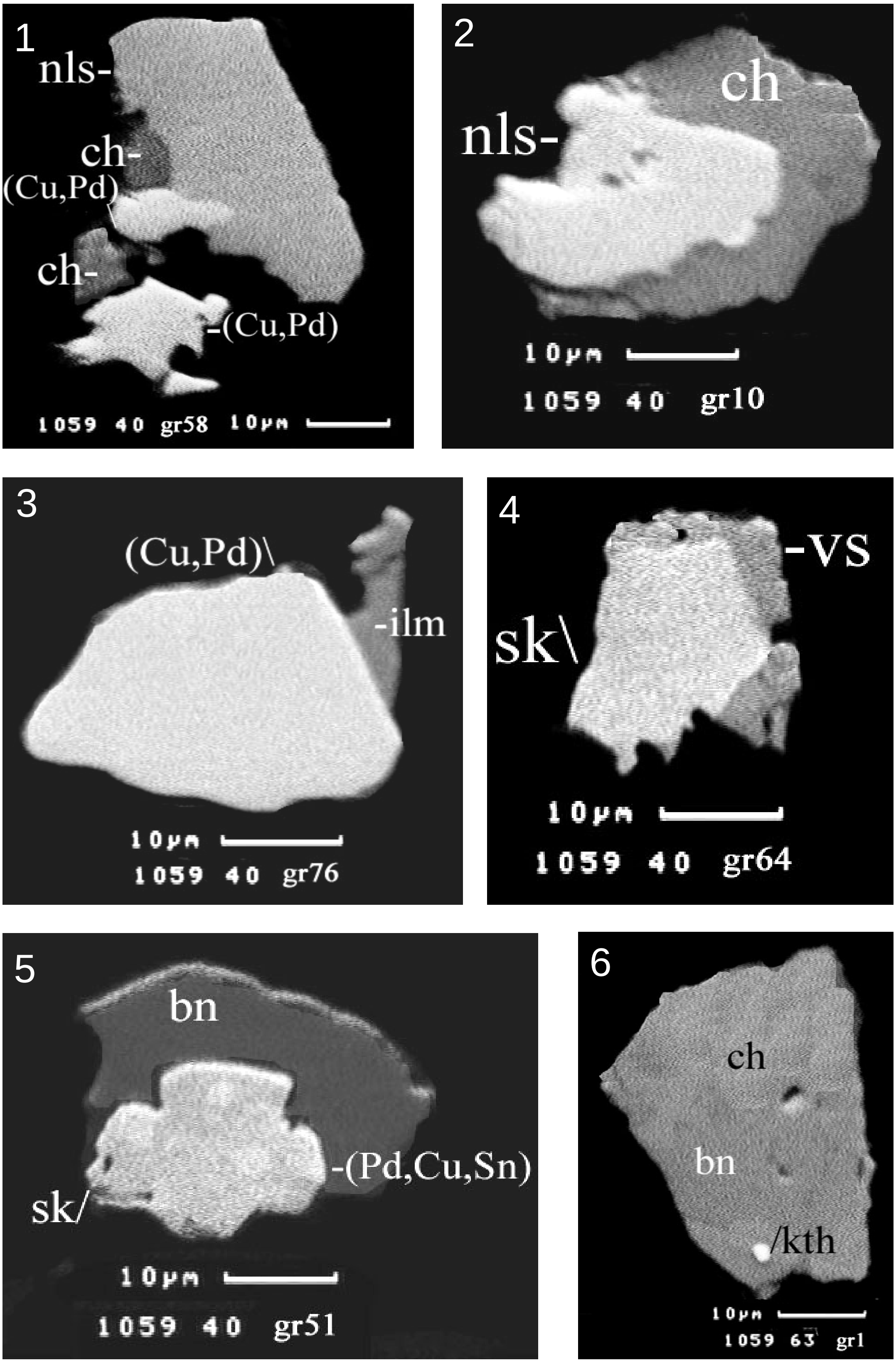

25
sk/
10μm
1059 40 gr72
26
/sk
10μm
1059 40 gr34
27
-sk
10μm
1059 40 gr63
28
-sk
10μm
1059 40 gr5
29
sk\
1059 40 gr61 10μm
30
sk-
10μm
1059 40 gr59
31
sk/
10μm
1059 40 gr2
32
-sk
10μm
1059 40 gr39
33
sk\
10μm
1059 63 gr14

Plate 6



PGM grains containing nielsenite (nls; 1, 2) (Cu,Pd) alloy (1, 3), vasilite (vs; 4), (Pd,Cu,Sn) alloy (5) and keithconnite (kth; 6) in the HS- concentrates of sample 90-24 1059; polished section, SEM-image (BIE). Other abbreviations: bn: bornite; ch: chalcosine; ilm: ilmenite.