DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/92

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

Part 13: Sample 90-18 1012

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Abstract

The report presents the results of mineralogical investigations of the sample 90-18 1012 from the Platinova Reef precious metal mineralization in the Skaergaard intrusion. The sample originates from core 90-18 between depths of 1012 and 1013 m in the lower part of the Pd5 level of the mineralization. Assays give 1240 ppb Pd, 175 ppb Pt and 46 ppb and for the interval.

The sample weighing 720 g was crushed in small portions using a shatter box (200 ml) with small cavities. The preparation of the sample consisted of short periods of crushing (0.3-0.5 min) followed by sieving to remove the fine fraction (sieve -125 μm). The residual coarse fraction >125 μm was re-crushed until the entire sample has attained the desired maximum grain size.

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

The non-magnetic part of each grain size fraction from sample 90-18 1012 was then separated using the computer controlled hydroseparator devise CNT HS-11. Monolayer polished sections were prepared from each grain size fraction of heavy HS-concentrates. The polished sections (and one section of the bulk rock) were then investigated under the scanning electron microprobe. All magnetic fractions proved not to contain precious metal grains.

The gabbroic bulk rock of the sample 90-18 1012 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 – chalcosine (sometimes digenite) - (69 %), more rarely by chalcosine+bornite (31 %). Several of these droplets and sulphide grains contain inclusions of PGMs.

As the result of microprobe investigations of heavy mineral concentrates, we selected a representative suite of 116 grains of PGMs for more detailed studies. The dominating precious metal minerals are (Cu,Pd,Pt) alloys including: (1) skaergaardite– 81.8 vol. %, (2) unordered (Cu,Pd,Pt) alloy 7 vol. %, and (3) nielsenite 3.3 vol. %. These alloys show major chemical variations - from 6.9 to 52 at. % (Pd+Pt+Au) and include both – ordered (skaergaardite PdCu and nielsenite $PdCu_3$) and unordered alloys. Besides these 7 less common phases form ~ 8 % of all precious metal minerals of the sample. They include: vysotskite

(Pd,Cu)S (6.7 vol. %), unnamed $(Pd,Pt,Cu)_3S_2$ (0.4 vol. %), unnamed $(Cu,Pd)_{2+x}S$ (0.5 vol. %), keithconnite $(Pd,Cu)_3(Te,Pb)$ (0.1 vol. %), cabriite Pd_2CuSn (0.1 vol. %), atokite Pd_3Sn (<0.1 vol. %), (Pd,Cu,Pb) alloy (0.1 vol. %) and (Cu,Au)? alloy (<0.1 vol. %).

The grain size of PGE and Au minerals (ECD) varies from 1 to 40 μm, but fine grained particles are dominat and the average grain size is 17 μm.

Average composition of skaergaardite (80 analyses) is (wt. %): Pd 56.4, Pt 3.0, Au 3.5, Cu 31.0, Fe 3.3, Zn 0.6, Sn 0.1, Te 0.9, Pb 0.7 with a total 99.5;. The composition corresponds to the formula:

$$(Pd_{0.93}Au_{0.03}Pt_{0.03})_{0.99}(Cu_{0.86}Fe_{0.11}Zn_{0.02}Te_{0.01}Pb_{0.01})_{1.01}$$

The estimated bulk composition of the sample (assays of whole rock in brackets, ppb) is: Pd 1314 (1240), Au 74 (46), Pt 73 (175). Pd is concentrated in (Cu,Pd) alloys (~90 %) and the remaining ~10 % the Pd in the sulphides vysotskite, unnamed $(Cu,Pd)_{2+x}S$ and unnamed $(Cu,Pt,Pd)_3S_2$. Pt is distributed between (Cu,Pd,Pt) alloys (~92 %) and Cu-Pd-Pt sulphides (~8 %) too. Au is concentrated in (Cu,Pd,Au,Pt) alloys only.

The majority of the identified precious metal minerals form a single paragenesis together with the identified Cu-Fe sulphides.

Introduction

The report describes the mineralogy of sample 90-18 1012 from the lower part of the Pd5 level in the “Platinova Reef” of the Skaergaard intrusion (Andersen et al., 1998; Nielsen et al, 2005). The report is based on data obtained from concentrates produced using a new patented model of Hydroseparator CNT HS-11. The HS-concentrates were used for mono-layer polished sections. Together with one polished section of the bulk gabbro they were investigated under the electron microscope and electron microprobe (Camscan-4DV, Link AN-10 000). The report describes the grain characteristics, the parageneses and the compositional variations within the identified groups of minerals, alloys, sulphide droplets and bulk gabbro.

The investigation was carried out in 2008.

Sample 90-18, 1012

Sample 90-18 1012 was collected from BQ drill core #90-18, between depths of 1012 and 1013 m. The core was drilled with an azimuth of 0^o and an inclination of $–70^o$ from a location at 504 meters a.s.I, on the western slopes of Basistoppen. The sample does not collect the entire interval as it has previously been sampled for other purposes. The sample represents app. 1/3 of the diameter of the preserved core.

Sample 90-18, 1012 (720 g) is composed of oxide-rich tholeiitic gabbro. Assays for sample 90-18 1012 give 1240 ppb Pd, 46 ppb Au, and 175 ppb Pt for this interval.

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003). One polished section was prepared from a fragment of the sample (Plate 1), and all the rest of the material was processed. All the available core material was crushed to –125 µm. After complete grinding, the sample was passed through standard sieves with water (wet sieving): <40 µm (322.3 g) , 40-63 µm (226 g), 63-80 µm (45.6 g), 80-125 µm (102.1 g).followed by wet magnetic separation.

The powdered fractions <40 µm, 40-63 µm, 63-80 µm, 80-125 µm were then passed through hydroseparator CNT HS-11. The concentrates of heavy mineral enriched in precious metal phases were obtained using a new patented model of the computer controlled Hydroseparator CNT HS-11 and a newly patented glass separation tube (GST) (Rudashevsky & Rudashevsky, 2006 and 2007; see also web address cnt-mc.com). Finally, monolayered polished sections were produced from all fractions of heavy mineral HS-concentrates (Plate 2).

Results

Rock forming minerals and sulphide mineralogy

Silicates and FeTi- oxides

Silicate and FeTi-oxide minerals related to sulphide phases include: 1) *plagioclase I*, An_{44-} (Table 1, analysis 1) and *plagioclase II*, An_{62} (Table 1, analysis 2); 2) *monoclinic ferrous pyroxene*, Mg# = 0.62-0.68 (Table 1, analyses 3, 4); 3) *orthorhombic ferrous pyroxene*, Mg# = 0.51 (Table 1, analysis 5); 4) *fayalite*, Mg# = 0.47 (Table 1, analysis 6); 5) *ilmenite* (Table 1, analyses 7-9) and 7) *titaniferous magnetite* (Table 1, analyses 10, 11). Monoclinic and orthorhombic pyroxenes typical form exsolution textures (Plate 1).

The Fe-Ti-oxides occur as aggregates of 1-3 mm, anhedral grains. They fill space between grains of plagioclase and pyroxenes (see Plate 1). The gabbro exhebits the characteristic reaction relationships between cumulus and intercumulus phases (see also Holness et al., 2011) including rims of fayalite and plagioclase II (high An%) at the boundaries between accumulated grains of Fe-Ti-oxides and two-pyroxenes (Plate 1).

One grain of baddeleyite, 40 μm in size, was identified in the heavy mineral concentrate – Plate 3. It can be used for for dating purposes.

Sulphides

The gabbro is relatively poor in sulphides. Just one grain was found in thin section. It is composed of chalcosine and bornite with a skaergaardite inclusionand is enclosed in a pyroxenes chacaterised by exsolution (Plate 1, #*3-5*).

The non-magnetic heavy mineral concentrates are ilmenite-rich (> 97% ilm) and enriched by grains of sulphides and PGMs (see Plate 2). The sulphide grains are represented by droplet-like microglobules: chacosine (Plate 4, #*1-5 etc*) and chalcosne-bornite (Plate 4, #*14-17* etc) as well as irregular aggregates: chalcosine (Plate 4, #*6-13* etc), chalcosine-bornite (Plate 4, #*18-22* etc) and bornite (Plate 4 ,#*23, 24*) up to 0.1 mm.

The following rock-forming minerals are commonly found in the marginal parts of sulphide grains or PGM grains: (1) ilmenite (Plate 5, #*42-46*; Plate 7, #*14*), (2) clinopyroxenes (Plate 5, #*35, 36*), (3) magnetite (Plate 4, #*23, 24*); (3) chlorite (Plate 4, *11-13*; Plate 5, #*37-38*; Plate 8, *7-9*; Plate 9, #*5, 6*), (6) talc (Plate 5, #*39*), (7) ferrisaponite (Plate 5, #*40, 41*; Plate 8, #*11*) and (8) apatite (Plate 4, #*13*).

The majority (69 %) of sulphide grains are composed of chalcosine (sometimes digenite), with fewer composed of chalcosine (sometimes digenite)+bornite or bornite only (31 %). Bornite and chalcosine form classic exsolution textures inside the sulphide microglobules and grains (see Plate 4, #*14-22* etc.).

The compositions of chalcosine (Table 2, analyses 1-7, 9-12, 15-22, 25-27, 30, 31, 33-35, 37, 38, 40-44), bornite (Table 2, analyses 28, 29, 32, 36, 39, 45) and digenite (Table 2, analysis 8, 13, 14, 23, 24) are all close to being stoikiometric.

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

Recovery

Only one small 5 µm PGM grain of skaergaardite was found during a SEM study of the polished section of sample 90-18 1012. The skaergaardite grain is together with bornite enclosed in pyroxene aggregates (Plate 1, #*3-5*).
The heavy mineral concentrates of the sample, however, have yielded many precious metal grains. A representative selection of 116 grains of a wide size range (from <40 µm up to 80-125 µm) was studied in detail and In total, 10 different PGE and Au are recorded and described from sample 90-18, 1012 (see Table 3 and Figure 1). These include:

1. *skaergaardite* (Pd,Au,Pt)(Cu,Fe,Zn,Te,Pb) – 80 grains,
2. *alloy* (Cu,Pd,Pt) –12 grains
3. *alloy* (Cu,Pt,Pd) – 2 grains,
4. *nielsenite* (Pd,Au,Pt) $(Cu,Fe)_3$ – 4 grains,
5. *vysotskite* (Pd,Cu,Fe)S–16 grains,
6. *unnamed* $(Cu,Pt,Pd,Cu)_3S_2$ – 2 grains,
7. *unnamed* $(Cu,Pd,Pt)_{2+x}S$ – one grain,
8. *keithconnite* $(Pd,Cu)_3(Te,Pb)$ – one grain,
9. *atokite* $(Pd,Cu,Fe)_3Sn$ – 2 grains,
10. *alloy* (Cu,Au)? – one grains.

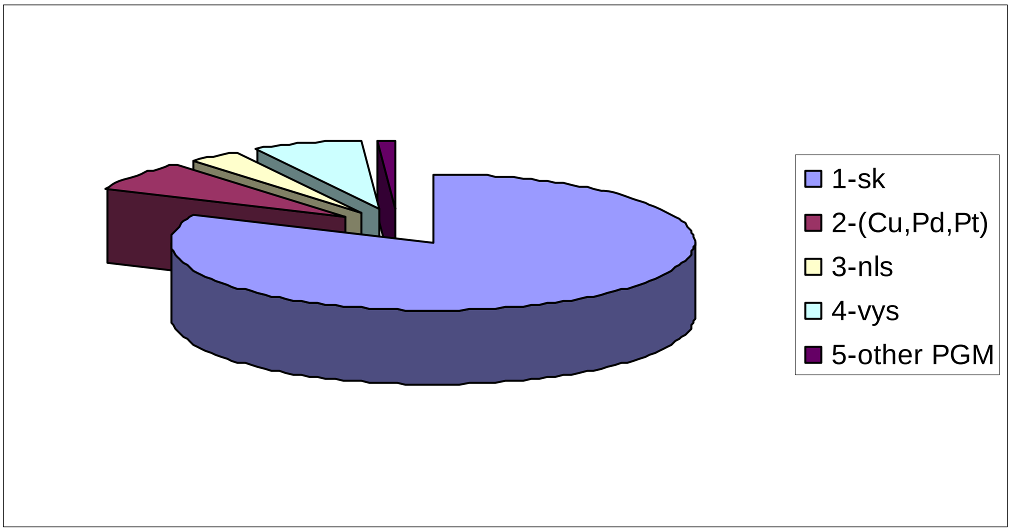

Figure 1: The volumetric proportions of precious metal minerals as calculated from the area of the grains of the minerals: 1) skaergaardite, 81.8 vol. %; 2) unordered (Cu,Pd,Pt) alloy, 7.0 vol. %; 3) nielsenite, 3.3 vol. %; 4) vysotskite, 6.7 vol. %; and 5) other PGMs, 1.2 vol. %.

Grain size

Grain sizes were measured by the effective diameter of the grains (ECD) using the imageJ ® software. They vary from 1 to 40 µm in size with an average of 17 µm (Table 4; Fig. 2).

The histogram of grain sizes (Fig. 2) shows the lognormal distribution for the statistical selection (n=116). According to this histogram, size of PGE and Au mineral grains are distributed as follows:

Grain size, µm	Number of grains
0-10	40
10-20	34
20-30	31
30-40	11

The SEIs (scanning electron images) show that majority of precious metal mineral grains are well preserved and have kept their primary shape and size (Plates 5-9). Grains have not been broken during production of the concentrates. Most PGM grains are inclusions in Cu-Fe sulphide globules and grains.

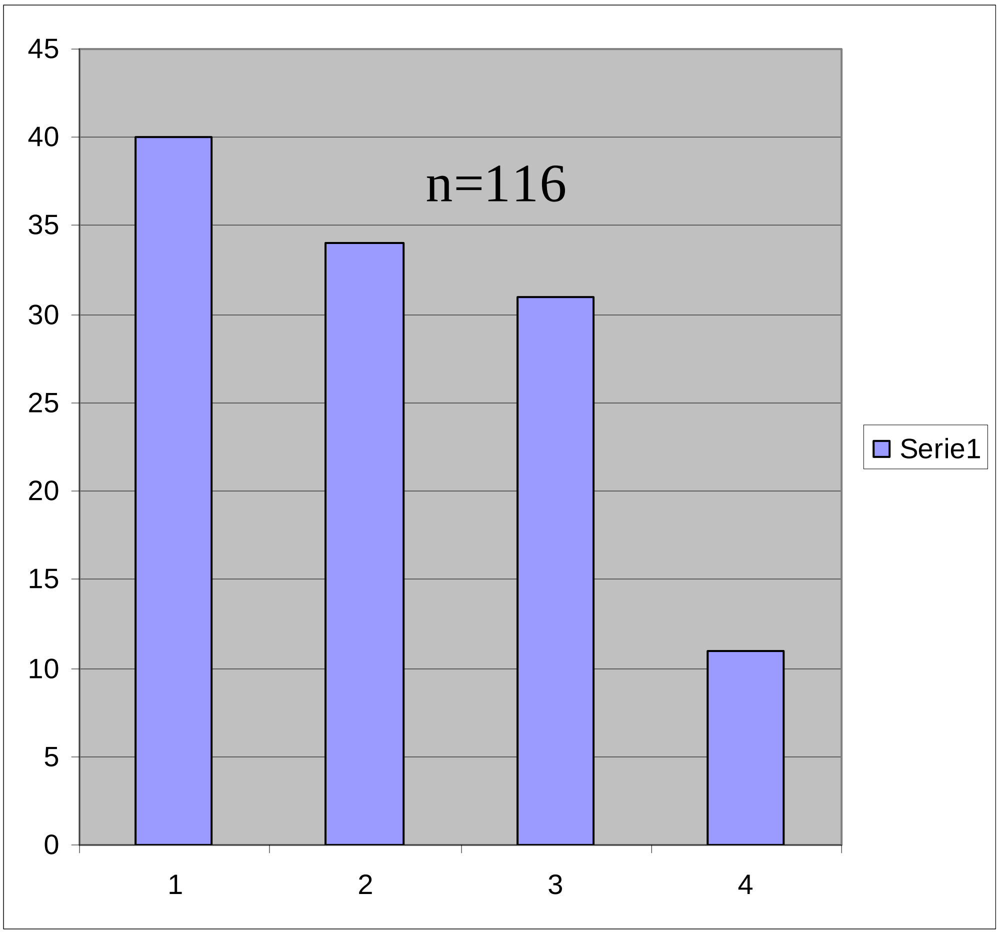

Figure 2: The size of 116 PGM grains in the heavy mineral concentrates of sample 90-18 1012. In the abscissa: 1) 0-10 µm, 2) 10-20 µm, 3) 20-30 µm, and 4) 30-40 µm.

Petrographic observations

An almost perfect separation of accessory minerals was achieved by the gentle crushing and disintegration of the sample. The method preserves primary grain sizes and characteristics and thus allows recovery of the most important information required for the reconstruction of genesis of the mineralisation..The concentrates provide full information for the reconstruction of the primary grain shapes and sizes, together with the relationships between mineralization and host rock and the parageneses.

In sample 90-18, 1012 the precious metal mineral grains occur in the following mineral associations shown in figure 3 and table 5.

Table 5.

Association	PGM-grains, number	PGM-grains, vol. %
bms	60	23.1
bms-L	8	18.1
L	27	34.7
L^+	2	2.6
sag	11	10.9
ag	8	10.6

Associations of PGE and Au mineral grains in heavy mineral concentrates of the sample 90-18 1012. **Bms** - intergrowths with base metal sulphides (chalcosine, bornite, digenite); **bms-L** - liberated particles with <10 % attached base metal sulphides; **L** - completely liberated (free) particles; **L^+**- more than one precious metal minerals completely liberated (free) particles, **sag** - sulphide and gangue (ilmenite, clinopyroxenes, chlorite, talc, ferrosaponite) attached to PGMs; **ag** - PGMs attached to gangue (ilmenite, ferrosaponite).

Precious metal minerals attached to bms (**bms**+**bms-L**+**sag** associations) form with 52.1% the dominatnt association of PGMs in the sample (see Fig 3). The proportion of completely liberated precious metal mineral grains (**$L+L^+$**) in the heavy mineral concentrate reach 37.3 %, and 10.6 % of the PGMs only are attached only to gangue (**ag** association).

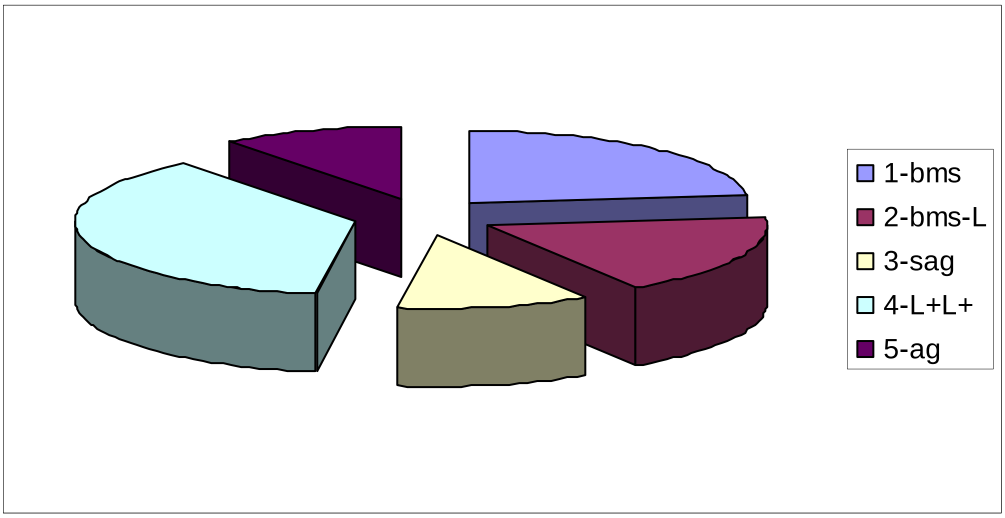

Figure 3: PGMs grouped by associations, sample 90-18, 1012; see Table 5. 1) 23.1 vol. % **(bms)** – PGMs attached to base metal sulphides; 2) 18.1 vol. % (**bms-L)** liberated PGM grains attached to base metal sulphides but less than 10 %; 3) 10.9 % (**sag),** PGMs attached to sulphides and gangue; 4**)** 37.3 % (**$L+L^+$**) completely liberated (free) particles of PGMs; and 5) 10.6 % (**ag**), PGMs attached to gangue.

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

1. different mineral associations (**bms, bms-L, sag, ag**) of skaergaardite-bearing grains (Plate 5);
2. completely liberated skaergaardite grains (Plate 6);
3. mineral associations other than skaergaardite, (Cu,Pd,Pt) alloys, unordered (Cu,Pd,Pt) alloys , and nielsenite (Plate 7);
4. vysotskite-bearing grains (Plate 8);
5. other PGM grains rare in the sample 90 -18 1012 (Plate 9).

Description and chemistry of precious metal minerals

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

The mineral skaergaardite (PdCu) was first defined as a mineral in samples from the skaergaard intrusion mineralization (Rudashevsky et. al., 2004). Skaergaardite is the main precious metal mineral in heavy concentrates of the sample 90-18 1012 (81.8 vol.%).

Description
Skaergaardite is found in the heavy mineral concentrates in the following forms:

1. dominant, intergrowths with base metal sulphides (Cu-Fe sulphides) - **bms** (Plate 5, #*1-26*; Plate 8, #*10, 12-16;* **bms-L** (Plate 5, #*27-34*; Plate 9, #*4*);
2. intergrowths with sulphide and gangue, **sag:** clinopyroxene (Plate 5, #*35, 36*), chlorite (Plate 5, #*37, 38*), talc (Plate 5, #*39*), ferrosaponite (Plate 5, #*41*: Plate 7*, #11*);
3. intergrowth with gangue, **ag**: ilmenite (Plate 5, #*42-46*), ferrosaponite (Plate 5, #*40*);
4. intergrowths with other PGMs – vysotskite (Plate 8, #*10-16*), nielsenite (Plate 7, #*16*), and unnamed $(Cu,Pd)_3S_2$ (Plate 9, #*4*);
5. liberated (free) grains: **L** (Plate 6, #*1-23*).

The skaergaardite-bearing sulphide grains occur very often as droplet-like masses (Plate 5, #*1-3, 5-7, 9, 11, 14, 18, 35, 38;* Plate 8, #*11, 12, 14*); and alternatively as irregular grains (Plate 5, #*4, 8, 10, 12, 13, 15-17, 19-26, 37, 41* etc).

Skaergaardite grains occur as:

1. isometric droplet-like grains with the rounded outlines or their aggregates (Plate 5, #*1-5, 8, 10, 27, 28, 37, 41*; Plate 8, #*11, 12, 15*);
2. euhedral crystals or partially euhedral grains (Plate 5, #*6, 7, 9, 11-19, 29, 35, 38*; Plate 8, #*10*);

3. irregular shape grains and their aggregates (Plate 5, #*20-26, 30-34, 36, 39, 40, 42-46*; Plate 6, #*1-23*; Plate 7, #*15*; Plate 8, #*13, 15, 16*; Plate 9, #*4*).

The relationships of skaergaardite and sulphide phases are following:

1. skaergaardite grains or aggregates localized at the margin of sulphide globules or aggregates (Plate 5, #*1-3, 5-7, 9-24, 26, 35, 37,38, 41;* Plate 8*, #10, 12, 14);*

skaergaardite grains, enclosed in sulphides (Plate 5, #*4, 25*, Plate 8*, #11*)*.*

Rock-forming minerals (ilmenite, clinopyroxene, chlorie, talc and ferrosaponite) are as a rule localized at the margin of skaergaardite grains (Plate 5, #*36, 39, 40, 42-46* etc).

The grain size of skaergaardite (80 grains) is 1 to 40 μm with an average of 18 μm (Table 3).

Mineral chemistry

The composition of skaergaardite was estimated from 80 analyses from 80 individual grains (Table 6, analyses 1-72). The average is (wt. %): Pd 56.4, Pt 3.0, Au 3.5, Cu 31.0, Fe 3.3, Zn 0.6, Sn 0.1, Te 0.9, Pb 0.7 with a total of 99.5 wt% and the following formula:

$$(Pd_{0.93}Au_{0.03}Pt_{0.03})_{0.99}(Cu_{0.86}Fe_{0.11}Zn_{0.02}Te_{0.01}Pb_{0.01})_{1.01}.$$

Typical substitutions in skaergaardite include: Pt up to 25 % (Table 6, analysis 18), Au up to 16 % (Table 6, analysis 34), Fe up to 5.7 % (Table 6, analysis 18), Zn up to 2 % (Table 6, analysis 78), Sn up to 4.1 % (Table 6, analysis 67), Te up to 4 % (Table 6, analysis 73), Pb up to 6.6 % (Table 6, analysis 62). Characteristic for the studied sample are substitutions of Au, Pt, Te, Fe and Pb.

The variation in the concentrations of Pt and Au in skaergaardite are given in table 7 and in figs 4 and 5.

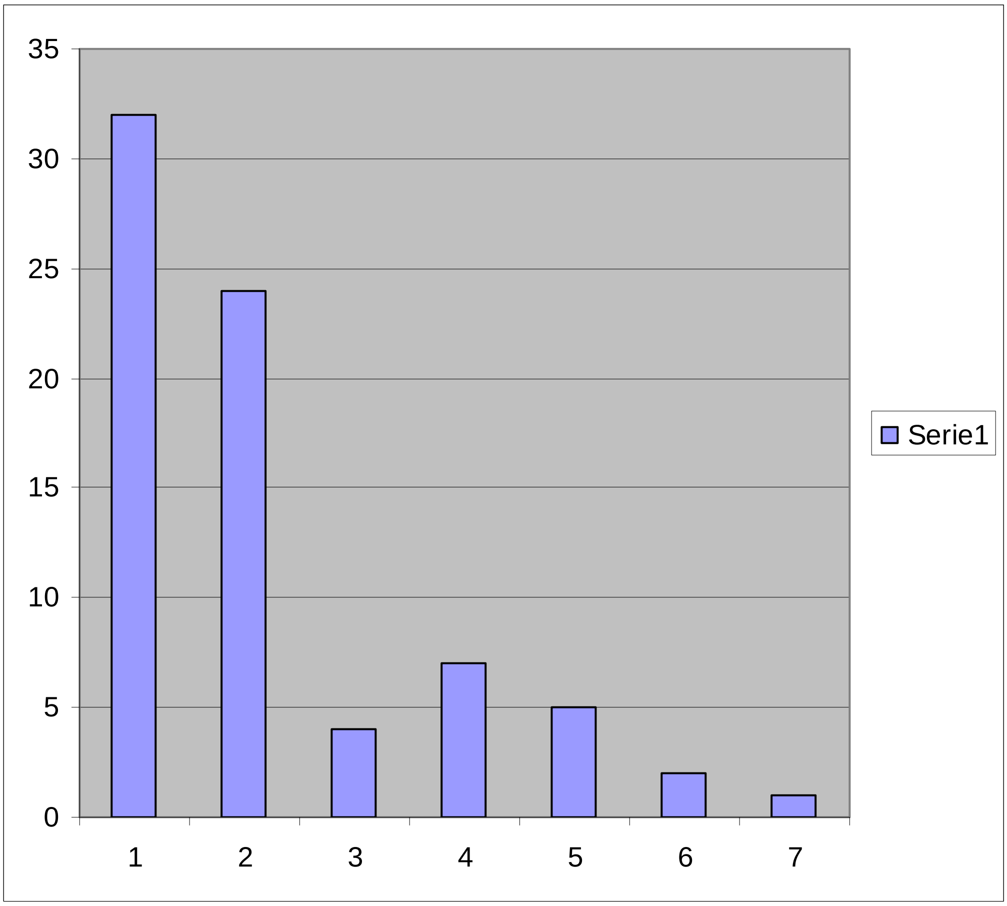

Figure 4: Histogram of Pt concentrations in skaergaardite grains (n=116), extracted in the heavy concentrates of the sample 90-18, 1012. In abscissa: 1: 0-1 % Pt, 2: 1-2.5 %, 3: 2.5-5 %, 4: 5-10 %, 5: 10-15 %, 6: 15-20 %, 7: 20-25 % Pt.

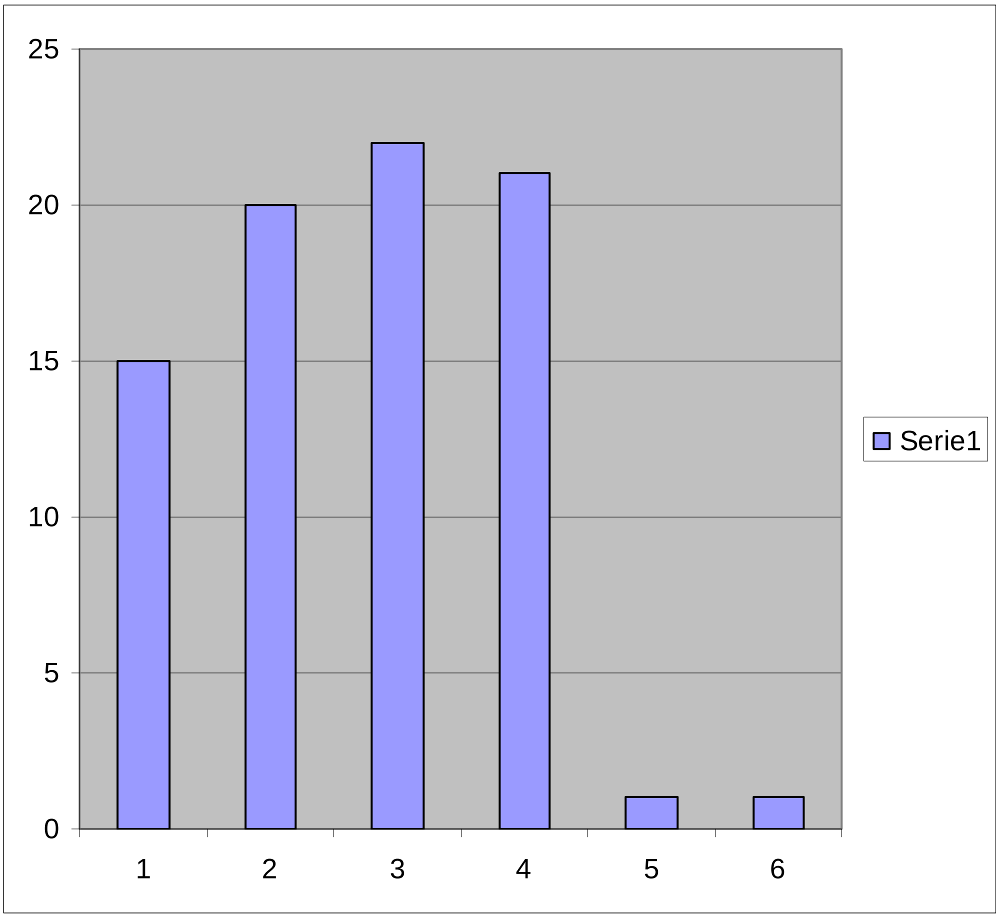

Figure 5: Histogram of Au concentrations in skaergaardite grains (n=116), extracted in the heavy concentrates of the sample 90-18, 1012. In abscissa: 1: 0-1 % Au, 2: 1-2.5 %, 3: 2.5-5 %, 4: 5-10 %, 5: 10-15 %, 6: 15-20 % Au.

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

Nielsenite $PdCu_3$ is recently described from the Skaergaard intrusion (McDonald et al., 2008).

Description

Nielsenite $PdCu_3$ is an ordered $(Pd,Au,Pt)(Cu,Fe)_3$ alloy in heavy concentrates of the sample 90-18 1012 (3.3 vol.% of all precious metal minerals). It is found in the heavy mineral concentrates in the following forms:

1. intergrowths with base metal sulphides (chalcosine), **bms** (Plate 7, #*15*; Table 8, analysis 2);
2. intergrowths with other PGMs, $\mathbf{L^+}$ – skaergaardite (Plate 7, #*16*, ; Table 8, analysis 4); atokite (Plate 7, #*18*; Table 8, analysis 1);
3. completely liberated (free) grain - **L** (Plate 5, #*16*; Table 8, analysis 3).

Sulphide globule with nielsenite are like droplets. Grains of nielsenite occur are:

a. isometric droplet-like grain with the rounded outlines (Plate 7, #*15*);
   or
b. irregular shape grains (Plate 7, #*16-18).*

The grain size of nielsenite (4 grains) is 11-27 µm with an average of 18 µm (Table 3).

Mineral chemistry
Based on four analyses (Table 8, analyses 1-4) the average composition of nielsenite (Table 8, analysis 5) is (wt. %): Pd 30.9, Pt 2.0, Au 3.3, Cu 62.6, Fe 0.6, Total 99.4. The composition corresponds to the formula

$$(Pd_{0.89}Au_{0.05}Pt_{0,03})_{0.97}(Cu_{3.00}Fe_{0.03})_{3.03}.$$

Typical admixtures in nielsenite are: Pt up to 5.5 %, Au up to 5.5 %, Fe up to 1.0 %.

Unordered alloys (Cu,Pd,Pt,Fe)

Description
Unordered (Cu,Pd,Pt) alloys (7.0 vol. % of all PGMs) occur in the heavy mineral concentrates in the following forms:

1. dominant type, in intergrowths with base metal sulphides (as a rule chalcosine, rarely chalcosine+bornite) - **bms** (Plate 7, #*1-10, 13*)*;*
2. in intergrowths with gangue (ilmenite) – **ag** (Plate 7, #*14*);
3. completely liberated (free) grains - **L** (Plate 7, #*11, 12*).

Sulphide grains with (Cu,Pd,Pt) alloys occur very often as droplets (Plate 6, #*1-4*); or irregular-shaped grains (Plate 7, #*9, 10).* Grains of these (Cu,Pd,Pt) alloys occur as:

1. isometric droplet-like grains with the rounded outlines (Plate 7, #*1-9*);
2. euhedral crystals (Plate 7, #*13, 14*);
3. irregular grains (Plate 7, #*10-12*)*.*

Grains of the unordered (Cu,Pd,Pt) alloys are localized at the margin of sulphide globules (Plate 7, #*1, 4, 7, 8, 9, 10*) or enclosed in sulphide aggregates (Plate 7, #*2, 3, 5, 6*).

The grain size of unordered (Cu,Pd,Pt) alloys (12 grains) is 3-26 µm with an average of 13 µm and for (Cu,Pt,Pd) alloys (2 grains) the sizes are 7 and 11 µm (Table 3).

Mineral chemistry
Three compositional groups can be identified In the group of unordered (Cu,Pd,Pt) alloys:

1. (Cu,Pd,Pt,Au) alloys in an interval 6.9-15.4 at. % Pd+Pt+Au, Pd>Pt (Table 9, analyses 1-12, average analysis - 13);
2. (Cu,Pt,Pd) alloys in an interval 13-17 at. % Pd+Pt+Au, Pt>Pd (Table 9, analyses 15, 16, average analysis - 17);
3. (Cu,Pd,Au) alloy, Pd+Au 38 at % (Table 9, analysis 14).

Vysotskite (Pd,Cu,Fe)S

Description

Vysotskite (6.7 vol. % of all PGMs) is found in the heavy mineral concentrates in the following forms:

1. Dominant type, in intergrowths with base metal sulphides (chalcosine, less commonly chalcosine+bornite) - **bms** (Plate 8, #*1-6, 10, 12-16)*;
2. In intergrowths with sulphide and gangue (chlorite) – **sag** (Plate 8, #*7-9, 11)*
3. In intergrowths with sulphides and other precious metal minerals, with skaergaardite (Plate 8, #*10-16*) and with (Cu,Au)? alloy (Plate 8, #*10*).

The vysotskite-bearing sulphide grains occur as a rule as irregular-shaped grains (Plate 8, #*1-11, 13, 15*) or rarely as droplet-like grains (Plate 8, #12, 14). Usually, vysotskite inclusions are adjunct to the margin of their host sulphide grains. Vysotskite occur as a rule as irregular grains (see Plate 8).

The grain size of vysotskite (16 grains) is 2-27 μm with an average of 11 μm (Table 3).

Mineral chemistry

The composition of vysotskite in 8 analyses from 8 grains are shown in Table 10 (analyses 1-8). AThe average composition of vysotskite (Table 10, analysis 9) is (wt. %): Pd 74.3, Cu 1.6, Fe 0.3, Ni 0.1, S 23.4, with a total of 99.7. The composition corresponds to the formula

$$(Pd_{0.96}Cu_{0.04}Fe_{0.01})_{1.01}S_{.1.00} .$$

Typical substitutions in vysotskite are Cu (up to 3.6 %), Ni (up to 0.8 %), and Fe (up to 1.2 %),.

Unnamed $(Cu,Pd,Pt)_{2+x}S$ and $(Cu,Pt,Pd)_3S_2$

PGE-bearing Cu-sulphides of variable composition found in several Cu sulphide grains (Table 3).

Two grains of Cu sulphides (chalcosine or digenite) contain droplet-like inclusion of PGE-bearing Cu sulphide $(Cu,Pd,Pt)_{2+x}S$ (Plate 5, #*20*; Plate 9, #*5, 6*; Table 10 , analyses 10, 11). The boundaries of these PGE-bearing droplets with matrix Cu sulphide are characterized by skaergaardite (Plate 5 #*20*; Table 6, analysis 6) or unnamed PGE sulphide mineral $(Cu,Pd,Pt)_3S_2$? (Plate 9, #*5, 6*; Table 10, analyses 12, 13).

Unnamed sulphide $(Cu,Pd)_3S_2$ was also found as inclusion in chalcosine located at the margin a skaergaardite grain (Plate 9, #*4*; Table 10, analysis 14).

Keithconnite $(Pd,Cu)_3(Te,Pb)$

Only one keithconnite grain of irregular shape of 5 µm (0.1 vol. % of all PGE – see Table 3) was found. It is enclosed in chalcosine (see Plate 9, #*2*; Table 11, analysis 3).

Atokite $(Pd,Cu)_3Sn$

Only two atokite-bearing grains of irregular sharpe (atokite is 0.1 vol. % of all PGM) were found (see Table 3). Atokite (identified by semi-quantitative microprobe analysis) occurs as a small grain (~3 µm) included in chalcosine (Plate 9, #*1*), and at the margin of a nielsenite grain (Plate 7, #*18*).

Cabriite Pd_2CuSn

Only one small (5 µm), anhedral grain of cabriite (0.1 vol. % of all PGE – see Table 3) was found. It is attached to a gain of (Cu,Pd) as inclusion in a chalcosine grain (see Plate 7, #*7*; Table 11, analysis 2).

(Pd,Cu,Pb) alloy

Only one grain of (Pd,Cu,Pb) alloy of irregular shape having 5 µm (0.1 vol. % of all PGE – see Table 3) was found as an inclusion in a chalcosine grain (see Plate 9, #*3*; Table 11, analysis 1).

(Cu,Au) alloy?

One almost euhedral grain enclosed in a droplet of bornite and chalcosine intergrowth is composed of an intergrowth of vysotskite and (Cu,Au)? Alloy (Plate 8.2, # 10). The grain is only identified in a semi-quantitative analysis.

Bulk composition of PGMs of the sample 90-18, 1012

The relative concentrations of Pd, Au and Pt of the sample 90-18 1012 can be calculated from the total concentration of precious metals, the determined recovery, the modal proportions and the compositions of the identified phases (Tables 3, 6-10). The estimated bulk composition of the sample (assay of whole rock in brackets) is (ppb): Pd 1314 (1240), Au

74 (46), Pt 73 (175). Pd is concentrated in (Cu,Pd) alloys (~90 %) and Pd sulphides (~10 %): vysotskite, and unnamed $(Cu,Pd)_{2+x}S$ and$(Cu,Pt,Pd)_3S_2$. Pt is also in (Cu,Pd,Pt) alloys (~92 %) and Cu-Pd-Pt sulphides (~8 %). Au is concentrated in (Cu,Pd,Au,Pt) alloys only.

Discussion

PGM-paragenesis

The extensive data shows that the dominant PGMs in the studied sample are (Cu,Pd) alloys: skaergaardite (81.8 vol. %), unordered (Cu,Pd) alloys (7 vol. %) and nielsenite (3.3 vol. %). Also, there are notable quantities of grains of Pd sulphides identified: vysotskite (6.7 vol. %) and unnamed PGE-bearing Cu sulphides – $(Cu,Pd)_2S$ and $(Cu,Pt,Pd)_3S_2$.

All the observations and the inter-grain relations (Plates 6-10) suggest that all PGEs are parts of a single paragenesis together with Cu-Fe sulphides. The Cu-Fe sulphides and precious metal minerals are synchronous and crystallized later than rock-forming minerals: plagioclase, clinopyroxene, orthopyroxene, ilmenite and titanic magnetite.

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, Au and Pt which was separated from Cu-Fe sulphide melt. Such relationships of sulphide and metallic phases are documented for (Cu,Pd) alloys within all range of variations of its chemical composition - from skaergaardite compositions to native copper type $(Cu,Pd)_{Cu}$ alloy compositions: 6.9-52 at.% Pd+Pt+Au.

The absolutely new and importan tobservation was made during the study of the sample. It is the presence of a second immiscible and PGE-rich (Pd and Pt) sulphide melt enclosed in Cu-Fe sulphide droplet – (see Plate 5, #*20*; Plate 9, #*5, 6*). It demonstrates that immiscible PGE-rich sulphide melt coexist with immiscible Cu-Fe melt in the Fe-rich interstitial melt in the Skaergaard mineralization. The primary PGE-riched sulphide melt is depleted in PGE during its crystallization which can be seen from the crystallization of skaergaardite or unnamed $(Pd,Cu,Pt)_3S_2$ at the boundary between the two immiscible sulphide melts.

It is noteworthy that minerals of just Au and Pt composition, as well as compositions of Pd with the other heavy metals (Pb, Sn, Te, As, Bi etc) are virtually absent in the studied sample (<2 vol. %). All these minor elements - together with Pd, Au and Pt - are included in (Cu,Pd) alloys.

The observations can suggest trapping of heavy metals - including precious metals - in sulphide melts from melt of fluid in perculating from bottom to the top of the intrusion during its crystallization. Such metal-bearing fluid should have been in equilibrium with silicate melt.

Alternatively, the sulphide globules are immiscible melts that act as sinks for precious metals in the order governed by distribution coefficients. During cooling and crystallization the melt would reach a two liquid field and give rise to immiscible PGE-Cu-sulphide melt (e.g., Karup-Møller et al., 19xx)

Summary

116 PGM-grains were found in the heavy mineral concentrates of sample 90-18 1012. The 720 g sample was processed using the patented hydroseparator CNT HS-11.

The dominating precious metal minerals are (Cu,Pd,Pt) alloys including: skaergaardite with 81.8 vol. %, (Cu,Pd,Pt) alloy with 7 vol. %, and nielsenite with 3.3 vol. %. These alloys vary in composition – with from 6.9 to 52 at. % Pd+Pt+Au. They include both – ordered (skaergaardite PdCu and nielsenite $PdCu_3$) and unordered alloys. The balance is made by 6 less common phases amounting to ~8 % of all precious metal minerals of the sample. These phases include: vysotskite (Pd,Cu)S (6.7 vol. %), unnamed $(Pd,Pt,Cu)_3S_2$ (0.4 vol. %), , unnamed $(Cu,Pd)_{2+x}S$ (0.5 vol. %), keithconnite $(Pd,Cu)_3(Te,Pb)$ (0.1 vol. %), cabriite Pd_2CuSn (0.1 vol. %), atokite Pd_3Sn (<0.1 vol. %), (Pd,Cu,Pb) alloy (0.1 vol. %) and (Cu,Au)? alloy (<0.1 vol. %).

The estimated bulk composition of the sample (assay of whole rock in brackets) is (ppb): Pd 1314 (1240), Au 74 (46), Pt 73 (175). Pd is concentrated in (Cu,Pd) alloys (~90 %) and Pd sulphides (~10 %): vysotskite, and unnamed $(Cu,Pd)_{2+x}S$ and $(Cu,Pt,Pd)_3S_2$. Pt is distributed between (Cu,Pd,Pt) alloys (~92 %) and Cu-Pd-Pt sulphides (~8 %) too. Au is concentrated in (Cu,Pd,Au,Pt) alloys only. All the observations and the inter-grain mineral relations suggest that all PGE and Au minerals are parts of a single paragenesis together with Cu-Fe sulphides.

The sulphide droplets contain droplets of PGMs and the characteristic structure 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 Cu-Fe sulphide melt. Sucha relationship between sulphide and metallic phases is documented by (Cu,Pd) alloys showing a wide range of variations of compositions from skaergaardite to native copper type $(Cu,Pd)_{Cu}$ alloy. The compositional range is from 6.9 to 52 at.% Pd+Pt+Au.

The presence of a second immiscible sulphide PGE-rich (Pd and Pt) melt inside Cu-Fe sulphide globules is documented and shows the formation of coexisting immiscible melts during the cooling and crystallization of the Cu-(Fe) sulphide melt. The melts were in equilibrium with silicate melt and demonstrate the syn-magmatic formation of PGE deposits during the late crystallization of the gabbroic intrusion.

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TABLES

Table 1. Chemical composition and formuli of silicates and oxides from oxide-rich tholeiitic gabbro, sample 90-18 1012

Analysis	1	2	3	4	5	6	7	8	9	10	11
Mineral	pl I	pl II	cpx	cpx	opx	ol	ilm	ilm	ilm	timt	timt
SiO_2	56.4	50.6	51.4	52.1	51.5	34.4	n.d.	n.d.	n.d.	n.d.	n.d.
TiO_2	n.d.	n.d.	0.2	0.4	0.3	n.d.	50.9	52.5	51.9	15.2	16.7
Al_2O_3	28.3	30.9	0.8	0.6	n.d.	n.d.	n.d.	n.d.	n.d.	3.1	2.8
V_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.5	0.4	0.3	1.5	1.6
Fe_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.0	0.9	1.9	34.4	31.6
FeO	n.d.	n.d.	11.1	12.5	27.6	43.3	42.6	43.6	43.7	44.8	45.5
MnO	n.d.	n.d.	0.3	0.3	0.5	0.6	0.6	0.5	0.5	n.d.	0.3
MgO	n.d.	n.d.	12.8	11.6	16.5	21.5	1.5	1.8	1.4	0.3	0.6
CaO	9.3	13.5	22.7	21.8	3.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Na_2O	6.3	4.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sum	100.3	99.4	99.3	99.3	99.4	99.8	99.1	99.7	99.7	99.3	99.1
Cations											
Si	2.53	2.32	1.96	1.93	1.98	1.00	-	-	-	-	-
Ti	-	-	0.01	0.01	0.01	-	0.97	0.99	0.98	0.43	0.47
Al	1.49	1.67	0.04	0.03	-	-	-	-	-	0.13	0.12
V							0.01	0.01	0.01	0.05	0.05
Fe3+	-	-	-	-	-	-	0.90	0.91	0.92	1.41	1.42
Fe2+	-	-	0.35	0.40	0.90	1.05	0.06	0.02	0.04	0.97	0.89
Fe	-	-	-	-	-	-	-	-	-	-	-
Mn	-	-	0.01	0.01	0.02	0.02	0.01	0.01	0.01	-	0.01
Mg	-	-	0.73	0.66	0.95	0.93	0.05	0.07	0.05	0.02	0.04
Ca	0.44	0.66	0.93	0.89	0.12	-	-	-	-	-	-
Na	0.54	0.39	-	-	-	-	-	-	-	-	-
Sum	5.00	5.04	4.03	3.93	3.98	3.00	2.00	2.01	2.01	3.01	3.00
O-basis	8.00	8.00	6.00	6.00	6.00	4.00	3.00	3.00	3.00	4.00	4.00
Mg#	-	-	0.68	0.62	0.51	0.47	-	-	-	-	-
An%	0.45	0.63	-	-	-	-	-	-	-	-	-

Abbreviations: pl: plagioclase; cpx: clinopyroxene; ol: olivine; ilm: ilmenite; timt: titanomagnetite.

Table 2. **Chemical composition and formulas of base metal sulphides in PGM-bearing globules of the heavy concentrates (sample 90-18, 1012)**

Analysis	Grain	Association	Mineral	wt % Cu	wt % Fe	wt % S	wt % sum	atomic proportions Cu	atomic proportions Fe	atomic proportions S	atomic proportions sum
1	40 gr a	ch	ch	77.7	1.5	20.4	99.6	*1.95*	*0.04*	*1.01*	*3.00*
2	40 gr b	ch	ch	79.3	1.2	20.3	100.8	*1.97*	*0.03*	*1.00*	*3.00*
3	40 gr c	ch	ch	78.9	0.5	19.9	99.3	*1.99*	*0.01*	*1.00*	*3.00*
4	40 gr d	ch	ch	79.1	0.6	20.2	99.9	*1.98*	*0.02*	*1.00*	*3.00*
5	40 gr e	ch	ch	79.4	0.4	20.0	99.8	*1.99*	*0.01*	*1.00*	*3.00*
6	40 gr f	ch	ch	79.8	0.6	20.4	100.8	*1.98*	*0.02*	*1.00*	*3.00*
7	40 gr g	ch+bn	ch	79.2	0.9	20.3	100.4	*1.97*	*0.03*	*1.00*	*3.00*
8	40 gr24	sk+dg	dg	75.4	1.7	22.4	99.5	*8.66*	*0.23*	*5.11*	*14.00*
9	40 gr25	sk+ch	ch	78.3	0.8	20.5	99.6	*1.96*	*0.02*	*1.02*	*3.00*
10	40 gr26	(Cu,Pd)Cu+ch	ch	79.6	0.0	20.1	99.7	*2.00*	*0.00*	*1.00*	*3.00*
11	40 gr28	vys+ch	ch	78.0	0.8	20.2	99.0	*1.97*	*0.02*	*1.01*	*3.00*
12	40 gr33	vys+ch	ch	78.6	0.5	19.9	99.0	*1.99*	*0.01*	*1.00*	*3.00*
13	40 gr43	sk+dg	dg	77.9	0.7	21.3	99.9	*9.01*	*0.09*	*4.89*	*14.00*
14	40 gr44	(Cu,Pd)Cu+dg	dg	78.2	0.0	21.2	99.4	*9.11*	*0.00*	*4.89*	*14.00*
15	40 gr45	(Pd,Pb,Cu)+ch	ch	78.9	1.0	19.9	99.8	*1.98*	*0.03*	*0.99*	*3.00*
16	40 gr66	vys+sk?+ch	ch	78.8	0.5	20.1	99.4	*1.98*	*0.01*	*1.00*	*3.00*
17	40 gr69	(Cu,Pd)Cu+ch	ch	78.6	1.0	20.3	99.9	*1.96*	*0.03*	*1.01*	*3.00*
18	40 gr79	vys+ch	ch	78.1	1.4	20.4	99.9	*1.95*	*0.04*	*1.01*	*3.00*
19	40 gr81	sk+ch	ch	77.5	1.1	20.3	98.9	*1.95*	*0.03*	*1.01*	*3.00*
20	40 gr85	nls+ch	ch	79.3	0.8	19.9	100.0	*1.99*	*0.02*	*0.99*	*3.00*
21	40 gr91	sk+vys+ch+fspn	ch	79.4	0.7	20.2	100.3	*1.98*	*0.02*	*1.00*	*3.00*
22	40 gr96	(Cu,Pt)Cu+ch	ch	78.4	0.6	20.1	99.1	*1.98*	*0.02*	*1.01*	*3.00*
23	40 gr98	sk+dg	dg	75.9	1.7	21.6	99.2	*8.81*	*0.22*	*4.97*	*14.00*
24	40 gr99	$(Cu,Pd)_2S+(Pd,Pt,Cu)_3S_2$+dg	dg	75.6	3.0	21.3	99.9	*8.72*	*0.40*	*4.88*	*14.00*
25	40 gr101	(Cu,Pt)Cu+ch	ch	80.0	0.6	20.3	100.9	*1.98*	*0.02*	*1.00*	*3.00*
26	40 gr103	cb+(Cu,Pd)Cu+ch	ch	78.8	0.5	20.0	99.3	*1.99*	*0.01*	*1.00*	*3.00*
27	80 gr1	sk+ch+bn	ch	79.2	0.5	20.1	99.8	*1.99*	*0.01*	*1.00*	*3.00*
28	80 gr1	sk+ch+bn	bn	63.8	11.0	25.6	100.4	*5.02*	*0.99*	*3.99*	*10.00*

Table 2 continued

Analysis	Grain	Association	Mineral	wt % Cu	Fe	S	Total	atomic proportions Cu	Fe	S	Total
29	80 gr1a	ch+bn	bn	62.9	11.2	25.5	99.6	*4.98*	*1.01*	*4.01*	*10.00*
30	80 gr1a	ch+bn	ch	78.8	0.8	20.1	99.7	*1.98*	*0.02*	*1.00*	*3.00*
31	80 gr3b	ch+bn	ch	79.4	0.5	20.3	100.2	*1.98*	*0.01*	*1.00*	*3.00*
32	80 gr3b	ch+bn	bn	63.9	10.7	25.5	100.1	*5.05*	*0.96*	*3.99*	*10.00*
33	80 gr3c	ch	ch	79.9	0.0	20.2	100.1	*2.00*	*0.00*	*1.00*	*3.00*
34	80 gr3d	ch	ch	80.0	0.0	20.2	100.2	*2.00*	*0.00*	*1.00*	*3.00*
35	80 gr4	(Cu,Pd)sk+ch	ch	80.3	0.0	20.4	100.7	*2.00*	*0.00*	*1.00*	*3.00*
36	125 gr a	bn+ch	bn	62.4	11.5	25.1	99.0	*4.99*	*1.05*	*3.97*	*10.00*
37	125 gr b	bn+ch	ch	79.1	0.0	19.9	99.0	*2.00*	*0.00*	*1.00*	*3.00*
38	125 gr d	bn+ch	ch	78.1	1.3	20.0	99.4	*1.96*	*0.04*	*1.00*	*3.00*
39	125 gr d	bn+ch	bn	64.0	10.6	25.1	99.7	*5.09*	*0.96*	*3.95*	*10.00*
40	125 gr1	kth+ch	ch	79.3	0.4	20.0	99.7	*1.99*	*0.01*	*1.00*	*3.00*
41	125 gr1a	ch	ch	79.1	0.4	20.0	99.5	*1.99*	*0.01*	*1.00*	*3.00*
42	125 gr1b	ch	ch	79.1	0.0	20.0	99.1	*2.00*	*0.00*	*1.00*	*3.00*
43	125 2b	ch+bn	ch	79.5	0.4	20.2	100.1	*1.99*	*0.01*	*1.00*	*3.00*
44	125 gr2c	ch+bn	ch	78.9	0.3	19.9	99.1	*1.99*	*0.01*	*1.00*	*3.00*
45	125 gr2c	ch+bn	bn	62.3	10.8	25.3	99.3	*5.03*	*0.98*	*3.99*	*10.00*

Abbreviations: ch: chalcosine; bn: bornite; dg: digenite; sk: skaergaardite; (Cu,Pd)Cu: alloy; vys: vysotskite; (Pd,Pb,Cu): alloy; nls: nielsenite; fspn: ferrosaponite; $(Cu,Pd)_2S$: unnamed mineral; $(Pd,Pt,Cu)_3S_2$: unnamed mineral; (Cu,Pt)Cu: alloy; (Cu,Pd)sk: alloy.

Table 3. Precious metal minerals in heavy concentrates of the sample 90-18 1012

N	Mineral	General formula	Number of grains	Grain size, µm min	max	average	Vol. %
1	Skaergaardite	(Pd,Au,Pt)(Cu,Fe,Zn,Te,Pb)	80	1	40	18	81.8
2	Alloy	(Cu,Pd,Pt)	12	2	26	13	6.6
3	Alloy	(Cu,Pt,Pd)	2	7	11	9	0.4
4	Nilsenite	$(Pd,Au,Pt)(Cu,Fe)_3$	2	3	18	12	3.3
5	Vysotskite	(Pd,Cu,Fe)S	16	2	27	11	6.7
6	Unnamed	$(Cu,Pt,Pd)_3S_3$	2	1	10	8	0.4
7	Unnamed	$(Cu,Pd,Pt)_{2+x}S$	1			15	0.5
8	Keithconnite	$(Pd,Cu)_3(Te,Pb)$	1			5	0.1
9	Atokite	$(Pd,Cu)_3Sn$	2	3	3	3	0.1
10	Cabriite	Pd_2CuSn	1			5	0.1
11	Alloy	(Cu,Au)	1			2	<0,1

Table 4. Size and association of precious metal mineral grains in sample 90-18 1012

N	Grain	Association	Type	Mineral	Area, μm^2	ECD, µm	Note- grains:S
1	125-1	kth-ch	bms	kth	17	4.7	
2	125-2	sk-vys-bn	bms	vys	486	24.9	
3	125-2	sk-vys-bn	bms	sk	275	18.7	
4	125-2	sk-vys-bn	bms	total	761	31.1	
5	40-100	sk-ilm	ag-L	sk	1222	39.5	
6	40-101	(Cu,Pd)-ch	bms	(Cu,Pd)	52	8.1	
7	40-102	sk+ch	bms-L	sk	1169	38.6	
8	40-103	cb-(Cu,Pd-ch)	bms	cb	21	5.2	
9	40-103	cb-(Cu,Pd-ch)	bms	(Cu,Pd)	200	16.0	
10	40-103	cb-(Cu,Pd-ch)	bms	total	221	16.8	
11	40-103a	sk-ch	bms	sk	60	8.7	
12	40-104	sk	L	sk	546	26.4	
13	40-105	sk-ch-bn	bms	sk	78	10.0	
14	40-106	sk-(Pd,Cu)3S2-ch	bms-L	sk	854	33.0	
15	40-106	sk-(Pd,Cu)3S2-ch	bms-L	(Pd,Cu)3S2	46	7.7	
16	40-106	sk-(Pd,Cu)3S2-ch	bms-L	total	900	33.9	
17	40-107	sk-ch	bms-L	sk	1049	36.6	
18	40-108	sk+nls	Lp	sk	60	8.7	
19	40-108	sk+nls	Lp	nls	562	26.8	
20	40-108	sk+nls	Lp	total	622	28.1	
21	40-109	(Cu,Pd)-ch	bms	(Cu,Pd)	190	15.6	
22	40-10	sk-bn	bms-L	sk	610	27.9	
23	40-110	sk-ch-bn	bms	sk	37	6.9	
24	40-111	sk	L	sk	467	24.4	
25	40-112	sk-bn-ch	bms	sk	36	6.8	
26	40-11	sk-ch-bn	bms	sk	291	19.3	
27	40-12	sk-vys-bn-ch	bms	sk	510	25.5	
28	40-12	sk-vys-bn-ch	bms	vys	28	6.0	
29	40-12	sk-vys-bn-ch	bms	total	538	26.2	
30	40-13	sk-ch-bn	bms	sk	54	8.3	

Table 4 continued

N	Grain	Association	Type	Mineral	Area, μm2	ECD, μm	Note- grains:S
31	40-14	at-ch	bms	at	7	3.0	
32	40-15	vys-ch-chl	sag	vys	11	3.7	
33	40-16	(Cu,Pd)-ch-bn	bms	(Cu,Pd)	208	16.3	
34	40-18	sk+ch	bms	sk	45	7.6	
35	40-19	sk-ch-bn	bms	sk	104	11.5	
36	40-1	sk+ch	bms	sk	337	20.7	
37	40-20	sk+ch	bms	sk	93	10.9	
38	40-21	sk	L	sk	296	19.4	
39	40-22	sk	L	sk	320	20.2	
40	40-24	sk-dg	bms-L	sk	382	22.1	
41	40-25	sk-ch	bms	sk	27	5.9	3 grains: 25, 1, 1
42	40-26	(Cu,Pd)-ch	bms	(Cu,Pd)	24	5.5	
43	40-27	vys-ch	bms	vys	74	9.7	
44	40-28	vys-ch	bms	vys	34	6.6	
45	40-29	sk-ilm	ag	sk	90	10.7	
46	40-2	sk	L	sk	635	28.4	2 grains: 605, 30
47	40-30	(Cu,Pd)	L	(Cu,Pd)	502	25.3	
48	40-31	sk	L	sk	45	7.6	2 grains: 43, 2
49	40-32	nls-at	Lp	at	6	2.8	
50	40-32	nls-at	Lp	nls	236	17.3	
51	40-32	nls-at	Lp	total	240	17.5	
52	40-33	vys-ch	bms	vys	19	4.9	
53	49-34	sk	L	sk	327	20.4	
54	40-35	sk	L	sk	285	19.1	
55	40-36	sk-ilm	ag	sk	156	14.1	2 grains: 98, 58
56	40-37	sk-ch-bn	bms	sk	15	4.4	
57	40-38	sk-bn-ch	bms	sk	11	3.7	
58	40-39	sk-ch-fspn	sag	sk	204	16.1	
59	40-3	vys-ch	sag	vys	12	3.9	
60	40-40	sk	L	sk	379	22.0	
61	40-41	sk-bn-ch	bms	sk	354	21.2	
62	40-42	sk	L	sk	367	21.6	
63	40-43	sk-ch	bms	sk	93	10.9	

Table 4 continued

N	Grain	Association	Type	Mineral	Area, µm2	ECD, µm	Note- grains:S
64	40-44	(Cu,Pd)-ch	bms	(Cu,Pd)	64	9.0	
65	40-45	(Pd,Pb,Cu)-ch	bms	(Pd,Pb,Cu)	20	5.0	
66	40-46	sk-vys-ch	bms	vys?	51	8.1	21 grains: 20, 21, 10, <2
67	40-47	sk	L	sk	292	19.3	
68	40-48	sk-ch-srp	sag	sk	1036	36.3	
69	40-49	sk-ch	bms	sk	4	2.3	
70	40-50	sk-ch-bn	bms	sk	67	9.2	
71	40-51	sk	L	sk	420	23.1	
72	40-52	sk	L	sk	420	23.1	
73	40-53	sk-ch-chl	sag	sk	517	25.7	
74	40-54	sk	L	sk	393	22.4	
75	40-55	sk-bn-ch	bms	sk	43	7.4	
76	40-56	sk-ilm	ag	sk	370	21.7	
77	40-58	vys-ch	bms	vys	29	6.1	
78	40-59	(Cu,Pd)	L	(Cu,Pd)	545	26.3	
79	40-5	sk-ch	bms-L	sk	237	17.4	
80	40-60	sk-bn	bms-L	sk	461	24.2	
81	40-61	vys-ch-chl	sag	vys	31	6.3	4 grains: 13, 10, 6, 2
82	40-62	sk-ch-chl	sag	sk	30	6.2	
83	40-63	sk	L	sk	415	23.0	
84	40-64	sk-ch-bn	bms	sk	84	10.3	
85	40-65	sk-ilm	ag	sk	106	11.6	3 grains: 99, 3, 4
86	40-66	vys-sk?-ch	bms	vys	412	22.9	
87	40-67	sk	L	sk	135	13.1	2 grains: 127, 8
88	40-69	(Cu,Pd)-ch	bms	(Cu,Pd)	8	3.2	
89	40-70	sk	L	sk	282	19.0	
90	40-71	sk	L	sk	301	19.6	
91	40-72	sk-bn-ch	bms	sk	9	3.4	
92	40-73	sk	L	sk	61	8.8	
93	40-74	(Cu,Pd)-ch	bms	(Cu,Pd)	65	9.1	
94	40-76	sk	L	sk	1130	37.9	
95	40-77	(Cu,Pt)-ilm	ag	(Cu,Pt)	34	6.6	
96	40-78	sk	L	sk	473	24.5	

Table 4 continued

N	Grain	Association	Type	Mineral	Area, μm^2	ECD, μm	Note- grains:S
97	40-79	vys-ch	bms	vys	32	6.4	
98	40-7	sk-vys-ch	bms-L	sk	485	24.9	2 grains: 200,285
99	40-7	sk-vys-ch	bms-L	vys	584	27.3	
100	40-7	sk-vys-ch	bms-L	total	1069	36.9	
101	40-80	sk-bn-ch-cpx	sag	sk	34	6.6	
102	40-81	sk-ch	bms	sk	355	21.3	5 grains: 351, 1, 1, 1, 1
103	40-83	sk	L	sk	701	29.9	
104	40-85	nls-ch	bms	nls	170	0.0	
105	40-86	sk-ch	bms	sk	253	18.0	2 grains: 249, 4
106	40-87	sk-fspn	ag	sk	236	17.3	
107	40-88	(Cu,Pt)-ch	bms	(Cu,Pt)	91	10.8	
108	40-89	sk-ch	bms	sk	70	9.4	
109	40-8	sk-$(Cu,Pd)_2S$-ch	bms	sk	155	14.1	
110	40-90	sk-ch-cpx	sag	sk	740	30.7	
111	40-91	sk-vys-ch-fspn	sag	sk	471	24.5	
112	40-91	sk-vys-ch-fspn	sag	vys	206	16.2	
113	40-91	sk-vys-ch-fspn	sag	total	677	29.4	
114	40-92	sk-ch-bn	bms	sk	437	23.6	
115	40-93	sk-ch-bn	bms	sk	50	8.0	
116	40-94	nls	L	nls	103	11.5	
117	40-95	sk	L	sk	329	20.5	
118	40-96	(Cu,Pd)-ch	bms	(Cu,Pd)	80	10.1	
119	40-97	sk-fspn	ag-L	sk	1256	40.0	
120	40-98	sk-dg	bms	sk	51	8.1	
121	40-99	$(Cu,Pd)_2S$-$(Pd,Cu,Pt)_3S_2$-dg-chl	sag	$(Pd,Cu,Pt)_3S_2$	78	10.0	10 grains: 10, 13, 16, 6, 7, 8, 12, 3, 2, 1
122	40-99	$(Cu,Pd)_2S$-$(Pd,Cu,Pt)_3S_2$-dg-chl	sag	$(Cu,Pd)_2S$	174	14.9	
123	40-99	$(Cu,Pd)_2S$-$(Pd,Cu,Pt)_3S_2$-dg-chl	sag	total	252	17.9	
124	40-9	sk-ch	bms	sk	4	2.3	
125	63-1	sk	L	sk	1039	36.4	
126	63-2	vys-ch	bms	vys	68	9.3	
127	80-1	sk-ch-bn	bms	sk	151	13.9	
128	80-2	sk-bn-ch	bms	sk	275	18.7	

Table 4 continued

N	Grain	Association	Type	Mineral	Area, µm^2	ECD, µm	Note- grains:S
129	80-3	vys-sk-(Cu,Au)-ch-bn	bms	(Cu,Au)	8	3.2	
130	80-3	vys-sk-(Cu,Au)-ch-bn	bms	sk	290	19.2	
131	80-3	vys-sk-(Cu,Au)-ch-bn	bms	vys	110	11.8	
132	80-3	vys-sk-(Cu,Au)-ch-bn	bms	total	408	22.8	
133	80-4	(Cu,Pd)-ch	bms	(Cu,Pd)	211	16.4	

Abbreviations kth: keithconnite; ch: chalcosine; vys: vysotskite; bn: bornite; sk: skaergaardite; (Cu,Pd): alloy; ilm: ilmenite; cb: cabriite (Cu,Pd-ch): alloy; $(Pd,Cu)_3S_2$; nls: nielsenite; at: atokite; chl: chlorite; fspn: ferrosaponite; (Pd,Pb,Cu): alloy; $(Cu,Pd)_2S$: unnamed mineral; (Cu,Au): alloy; (Cu,Pt): alloy.

Table 5

is enclosed in the text

Table 6 Composition of Skaergaardite.

Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Grain	40 gr1	40 gr2	40 gr5	40 gr6	40 gr7	40 gr8	40 gr10	40 gr11	40 gr12	40 gr13	40 gr18	40 gr19	40 gr20	40 gr21	40 gr22
Association	sk+ch	sk	sk+ch	sk+ch	sk+vys+ch	sk+ch+ $(Cu,Pd)_2S$	sk+bn	sk+bn+ch	sk+vys+ bn+ch	sk+ch+bn	sk+ch	sk+ch+bn	sk+ch	sk	sk
Pd	58.9	56.7	57.7	50.3	54.3	56.0	58.3	60.0	57.5	39.9	44.8	57.2	54.3	54.1	58.5
Pt	0.0	1.1	2.2	13.4	1.8	0.0	1.9	0.0	1.5	16.2	19.3	3.8	8.2	1.1	0.0
Au	4.4	5.6	3.0	0.0	7.9	6.2	1.1	1.9	3.1	7.1	1.6	0.0	0.0	7.9	4.3
Cu	30.8	30.9	30.4	29.5	30.4	31.9	31.9	31.9	30.6	30.6	27.6	33.0	32.3	32.0	31.7
Fe	3.3	2.6	5.1	5.1	3.0	3.3	3.5	2.3	4.6	3.9	5.1	3.6	3.9	2.3	4.0
Zn	1.7	1.7	0.0	0.0	0.0	1.1	0.4	0.0	0.0	0.5	0.4	0.0	1.6	0.6	0.0
Sn	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	0.0	0.0
Te	0.5	1.2	1.0	0.0	0.9	0.9	2.6	0.0	1.5	1.7	0.7	0.0	0.0	1.4	1.1
Pb	0.0	0.0	0.0	1.1	1.5	0.0	0.0	3.1	0.9	0.0	0.0	2.2	0.0	0.0	0.0
sum	99.6	99.8	99.4	99.4	99.8	99.4	99.7	99.2	99.7	99.9	99.5	99.8	100.3	99.4	99.6
Atomic proportions															
Pd	0.96	0.94	0.95	0.86	0.92	0.92	0.95	1.00	0.94	0.70	0.79	0.93	0.88	0.91	0.95
Pt	0.00	0.01	0.02	0.12	0.02	0.00	0.02	0.00	0.01	0.15	0.19	0.03	0.07	0.01	0.00
Au	0.04	0.05	0.03	0.00	0.07	0.05	0.01	0.02	0.03	0.07	0.02	0.00	0.00	0.07	0.04
Cu	0.84	0.86	0.83	0.84	0.87	0.88	0.87	0.89	0.84	0.90	0.82	0.90	0.88	0.90	0.87
Fe	0.10	0.08	0.16	0.16	0.10	0.10	0.11	0.07	0.15	0.13	0.17	0.11	0.12	0.07	0.13
Zn	0.05	0.05	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.01	0.01	0.00	0.04	0.02	0.00
Sn	0.00	0.16	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
Te	0.01	0.01	0.01	0.00	0.01	0.01	0.04	0.00	0.02	0.03	0.01	0.00	0.00	0.02	0.02
Pb	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.01	0.00	0.00	0.02	0.00	0.00	0.00
sum	2.00	2.16	2.00	1.99	2.00	1.99	2.01	2.01	2.00	1.99	2.01	1.99	1.99	2.00	2.01

Abbreviations: sk: skaergaardite; vys: vysotskite; nls: nielsenite; (Cu,Au)?: alloy; $(Cu,Pd)_2S$: unnamed mineral; $(Cu,Pd)_3S_2$: unnamed mineral; bn: bornite; ch: chalcosine; dg: digenite; ilm:ilmenite; fspn: ferrosaponite; serp: serpentine; chl: chlorite; pl: plagioclase; cpx: clinopyroxene.

Table 6 continued

Analysis	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Grain	40 gr23	40 gr24	40 gr25	40 gr29	40 gr31	40 gr34	40 gr35	40 gr36	40 gr39	40 gr40	40 gr41a	40 gr41	40 gr42	40 gr43	40 gr47
Association	sk	sk+dg	sk+ch	sk+ilm	sk	sk	sk	sk+ilm	sk+ch+ fspn	sk	sk +bn+ch	sk +bn+ch	sk	sk+dg	sk
Pd	58.9	58	42.0	59.2	62.4	60.6	53.1	53.9	56.7	57.8	57.4	52.9	53.8	57.4	60.3
Pt	1.0	0.0	25.0	0.0	1.0	1.2	1.7	4.6	0.0	1.5	0.0	9.2	2.4	4.5	0.9
Au	3.8	5.4	0.0	5.4	0.9	1.3	9.2	6.3	6.3	4.9	5.5	1.1	7.0	0.0	2.0
Cu	31.1	30.4	27.0	30.3	29.4	30.3	31.3	30.3	32.3	30.3	31.8	29.9	31.1	31.1	30.7
Fe	3.2	4.6	5.7	2.5	4.2	3.3	2.1	3.4	3.0	2.8	3.4	4.1	2.2	3.7	3.7
Zn	1.5	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.9	1.1	1.5	1.0	0.0	1.2	1.3
Sn	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	1.3	0.0
Te	0.9	1.1	0.0	2.2	1.8	1.1	1.9	0.7	0.5	1.1	0.0	0.0	2.2	0.0	0.8
Pb	0.0	1.1	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	1.4	1.2	0.0	0.0
sum	100.4	100.6	99.7	99.6	100.1	100.0	99.3	99.2	99.7	99.5	99.6	99.6	99.9	99.2	99.7
Atomic proportions															
Pd	0.96	0.95	0.75	0.99	1.02	0.99	0.91	0.92	0.93	0.96	0.94	0.89	0.91	0.94	0.98
Pt	0.01	0.00	0.24	0.00	0.01	0.01	0.02	0.04	0.00	0.01	0.00	0.08	0.02	0.04	0.01
Au	0.03	0.05	0.00	0.05	0.01	0.01	0.08	0.06	0.06	0.04	0.05	0.01	0.06	0.00	0.02
Cu	0.85	0.83	0.81	0.85	0.80	0.83	0.90	0.86	0.89	0.85	0.87	0.84	0.89	0.85	0.84
Fe	0.10	0.14	0.19	0.08	0.13	0.10	0.07	0.11	0.09	0.09	0.11	0.13	0.07	0.12	0.11
Zn	0.04	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.02	0.03	0.04	0.03	0.00	0.03	0.03
Sn	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	0.02	0.00
Te	0.01	0.02	0.00	0.03	0.02	0.02	0.03	0.01	0.01	0.02	0.00	0.00	0.03	0.00	0.01
Pb	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
sum	2.00	2.00	1.99	2.00	2.00	2.00	2.01	2.00	2.00	2.00	2.01	1.99	1.99	2.00	2.00

Table 6 continued

Analysis	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Grain	40 gr48	40 gr50	40 gr51	40 gr52	40 gr53	40 gr54	40 gr55	40 gr56	40 gr57	40 gr60	40 gr62	40 gr63	40 gr 64	40 gr65	40 gr68
Association	sk+ch+srp	sk+ch+bn	sk	sk	sk+ch+chl	sk	sk+bn+ch	sk+ch+pl+ ilm	sk+vys+ch	sk+bn	sk+ch+chl	sk	sk+ch+bn	sk+ilm	sk
Pd	61.6	55.0	58.5	46.8	59.9	51.0	51.4	58.5	56.6	56.6	53.9	56.6	50.2	62.0	55.8
Pt	0.0	7.5	1.1	1.7	0.0	1.3	9.2	0.0	0.0	2.1	8.8	1.4	14.7	0.0	1.4
Au	0.0	0.0	3.5	16.0	2.9	7.0	1.4	4.1	4.7	5.3	1.0	5.9	0	3.3	6.6
Cu	31.0	30.2	30.9	31.4	31.8	33.6	30.7	32.5	32.5	30.5	29.9	29.5	28.5	29.5	31.3
Fe	3.2	1.9	3.1	1.6	2.7	5.2	4.2	2.9	3.5	2.4	4.9	4.7	5.0	4.2	2.7
Zn	1.5	0.4	0.4	0.0	0.9	0.9	1.3	0.0	0.5	0.8	1.0	0.0	0.9	0.8	0.5
Sn	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	0.0	0.0
Te	0.6	0.0	0.8	1.7	0.5	1.1	0.0	1.0	1.6	0.0	0.0	1.6	0.0	0.0	1.3
Pb	1.5	4.4	1.3	0.9	1.2	0.0	1.0	0.0	0.0	2.0	0.0	0.0	1.1	0.9	0.0
sum	99.4	99.4	99.6	100.1	99.9	100.1	99.2	99.0	99.4	99.7	99.5	99.7	100.4	100.7	99.6
Atomic proportions															
Pd	1.00	0.95	0.97	0.82	0.98	0.82	0.86	0.96	0.93	0.95	0.90	0.94	0.86	1.00	0.93
Pt	0.00	0.07	0.01	0.02	0.00	0.01	0.08	0.00	0.00	0.05	0.08	0.01	0.14	0.00	0.01
Au	0.00	0.00	0.03	0.15	0.03	0.06	0.01	0.04	0.04	0.05	0.01	0.05	0.00	0.03	0.06
Cu	0.84	0.87	0.86	0.92	0.87	0.91	0.86	0.90	0.89	0.86	0.83	0.82	0.81	0.80	0.88
Fe	0.10	0.06	0.10	0.05	0.08	0.16	0.13	0.09	0.11	0.08	0.16	0.15	0.16	0.13	0.09
Zn	0.04	0.01	0.01	0.00	0.02	0.02	0.04	0.00	0.01	0.02	0.03	0.00	0.02	0.02	0.01
Sn	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	0.00	0.00
Te	0.01	0.00	0.01	0.02	0.01	0.01	0.00	0.01	0.02	0.00	0.00	0.02	0.00	0.00	0.02
Pb	0.01	0.04	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.01	0.00
sum	2.00	2.00	2.00	1.99	2.00	1.99	1.99	2.00	2.00	2.03	2.01	1.99	2.00	1.99	2.00

Table 6 continued

Analysis	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Grain	40 gr70	40 gr71	40 gr73	40 gr75	40 gr76	40 gr78	40 gr80	40 gr81	40 gr83	40 gr84	40 gr86	40 gr87	40 gr89	40 gr90	40 gr91
Association	sk	sk	sk	sk	sk	sk	sk+ch+ bn+cpx	sk+ch	sk	sk	sk+ch	sk+fspn	sk+ch	sk+ch+ cpx	sk+vys+ch +fspn
Pd	48.3	53.2	58.3	54.2	61.8	57.8	56.5	58.4	57.2	58.6	61.5	60.8	61.7	60.0	61.1
Pt	0.0	0.0	0.9	0.0	0.0	0.0	5.3	1.2	0.9	0.0	0.0	0.0	0.0	1.9	0.0
Au	14.9	9.3	3.7	9.3	2.1	3.5	1.0	1.3	5.5	3.9	1.6	2.7	0.0	1.9	2.3
Cu	31.9	31.8	29.1	31.4	31.2	31.7	30.0	32.7	30.8	31.4	31.9	29.7	32.7	31.2	31.7
Fe	1.4	2.3	4.0	2.6	4.1	4.0	4.3	0.8	3.1	4.0	3.5	3.7	3.1	3.4	3.7
Zn	0.0	0.5	1.7	0.0	0.0	0.0	1.3	0.4	0.6	0.6	1.2	1.6	0.0	0.6	1.0
Sn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Te	2.7	1.9	0.7	1.9	1.1	2.2	0.0	2.9	1.0	1.6	0.0	1.1	0.9	0.8	0.5
Pb	0.0	0.0	0.9	0.0	0.0	0.0	1.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
sum	99.2	99.0	99.3	99.4	100.3	99.2	99.5	100.3	99.1	100.1	99.7	99.6	99.3	99.8	100.3
Atomic proportions															
Pd	0.84	0.90	0.96	0.92	1.00	0.95	0.93	0.97	0.95	0.95	0.99	0.99	1.00	0.98	0.98
Pt	0.00	0.00	0.01	0.00	0.00	0.00	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00
Au	0.14	0.08	0.03	0.08	0.02	0.03	0.01	0.00	0.05	0.03	0.01	0.02	0.00	0.02	0.02
Cu	0.93	0.90	0.81	0.89	0.84	0.87	0.83	0.90	0.86	0.85	0.86	0.81	0.88	0.85	0.85
Fe	0.05	0.07	0.13	0.08	0.12	0.12	0.14	0.03	0.10	0.12	0.11	0.12	0.10	0.11	0.11
Zn	0.00	0.01	0.05	0.00	0.00	0.00	0.03	0.01	0.02	0.02	0.03	0.04	0.00	0.02	0.03
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	0.01	0.00	0.00
Te	0.04	0.03	0.01	0.03	0.02	0.03	0.00	0.04	0.01	0.02	0.00	0.01	0.01	0.01	0.01
Pb	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum	2.00	1.99	2.01	2.00	2.00	2.00	2.00	1.99	2.00	1.99	2.00	1.99	2.00	2.01	2.00

Table 6 continued

Analysis	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Grain	40 gr92	40 gr93	40 gr95	40 gr97	40 gr98	40 gr100	40 gr102	40 gr103a	40 gr104	40 gr105	40 gr106	40 gr107	40 gr108	40 gr110	40 gr111
Association	sk+ch+bn	sk+ch+bn	sk	sk+fspn	sk+dg	sk+ilm	sk+ch	sk+ch	sk	sk+ch+bn	sk+ch+ $(Cu,Pd)_3S_2$	sk+ch	sk+nls	sk+ch+bn	sk
Pd	54.5	53.0	60.3	59.4	59.5	59.5	59.1	50.4	59.3	50.3	56.5	60.3	58.5	60.1	59.6
Pt	1.8	9.6	0.8	1.5	4.2	0.0	0.0	11.0	1.5	13.0	0.0	0.0	0.0	2.2	0.0
Au	6.5	0.0	0.9	2.4	0.0	2.1	1.3	1.1	2.5	0.9	6.1	2.5	2.5	1.1	4.8
Cu	30.6	29.6	32.2	29.9	30.4	31.6	33.0	29.7	30.7	28.3	31.6	31.6	31.2	30.9	31.1
Fe	3.2	0.9	3.0	3.7	3.8	3.4	1.5	5.4	3.0	5.0	3.8	2.9	0.8	2.4	3.5
Zn	0.0	0.0	0.0	0.7	1.5	0.0	0.0	0.7	0.6	1.0	0.0	1.0	0.0	1.5	0.8
Sn	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Te	2.4	0.0	2.3	1.7	0.0	1.0	0.0	0.0	1.9	0.0	1.6	1.3	4.0	0.0	0.0
Pb	0.9	6.6	0.0	0.0	1.0	1.5	0.0	1.4	0.0	0.9	0.0	0.0	2.4	2.4	0.0
sum	99.9	99.7	99.5	99.3	100.4	99.1	99.0	99.7	99.5	99.4	99.6	99.6	99.4	100.6	99.8
Atomic proportions															
Pd	0.92	0.94	0.98	0.98	0.97	0.98	0.97	0.85	0.98	0.86	0.93	0.98	0.99	0.99	0.97
Pt	0.02	0.09	0.01	0.01	0.04	0.00	0.00	0.10	0.01	0.12	0.00	0.00	0.00	0.02	0.00
Au	0.06	0.00	0.01	0.02	0.00	0.02	0.01	0.01	0.02	0.01	0.05	0.02	0.02	0.01	0.04
Cu	0.86	0.88	0.88	0.83	0.83	0.87	0.91	0.84	0.85	0.81	0.87	0.86	0.88	0.85	0.85
Fe	0.10	0.03	0.09	0.12	0.12	0.11	0.05	0.17	0.09	0.16	0.12	0.09	0.03	0.08	0.11
Zn	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.02	0.02	0.03	0.00	0.03	0.00	0.04	0.02
Sn	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Te	0.03	0.00	0.03	0.02	0.00	0.01	0.00	0.00	0.03	0.00	0.02	0.02	0.06	0.00	0.00
Pb	0.01	0.06	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.02	0.02	0.00
sum	2.00	2.00	2.00	2.00	2.01	2.00	2.00	2.00	2.00	2.00	1.99	2.00	2.00	2.01	1.99

Table 6 continued

Analysis	76	77	78	79	80
Grain	40 gr112	63 gr1	80 gr1	80 gr3	125 gr2
Association	sk+bn+ch	sk	sk+ch+bn	vys+sk+ch (Cu,Au)?	sk
Pd	50.1	59.1	59.5	58.3	57.2
Pt	12.4	0.0	0.0	0.0	0.0
Au	0.0	1.1	2.6	2.8	3.2
Cu	31.0	33.2	31.6	34.4	32.5
Fe	1.0	3.5	3.2	2.7	2.9
Zn	0.0	0.0	2.0	0.9	1.6
Sn	0.0	2.4	0.0	0.0	0.0
Te	0.0	0.0	0.8	0.0	0.8
Pb	5.7	0.0	0.0	0.0	0.0
sum	100.2	99.3	99.7	99.1	98.2
Atomic proportions					
Pd	0.88	0.95	0.96	0.94	0.94
Pt	0.12	0.00	0.00	0.00	0.00
Au	0.00	0.01	0.02	0.02	0.03
Cu	0.91	0.90	0.86	0.93	0.89
Fe	0.03	0.11	0.10	0.08	0.09
Zn	0.00	0.00	0.05	0.02	0.04
Sn	0.00	0.03	0.00	0.00	0.00
Te	0.00	0.00	0.01	0.00	0.01
Pb	0.05	0.00	0.00	0.00	0.00
sum	1.99	2.00	2.00	1.99	2.00

Table 7: Pt and Au concentrations in skaergaardite, sample 90-18 1012

Pt concentration Interval (wt %)	Grains in interval	Au concentration interval (wt%)	Grains in interval
0-1	32	0-1	15
1-2.5	24	1-2.5	20
2.5-5	4	2.5-5	22
5-10	7	5-10	21
10-15	5	10-15	1
15-20	2	15-20	1
20-25	1	-	-

Table 8. **Chemical composition and formuli for nielsenite hosted by PGM-grains in heavy concentrates of sample 90-18 1012.**

Analysis	1	2	3	4
Grain	40 gr32	40 gr85	40 gr94	40-108
Phase	nls	nls	nls	nls
Association	nls+at	nls+ch	nls	sk+nls
Composition, wt%				
Pd	27.5	30.2	34.4	31.3
Pt	0	5.3	1.8	1
Au	1.1	2.2	4.4	5.5
Cu	69.6	61.5	57.6	61.8
Fe	1	0.6	0.8	0
sum	99.2	99.8	99	99.6
atomic proportions				
Pd	0.75	0.87	1.01	0.91
Pt	0	0.08	0.03	0.02
Au	0.02	0.03	0.07	0.09
Cu	3.18	2.98	2.84	2.99
Fe	0.05	0.03	0.04	0
sum	4	3.99	3.99	4.01
Pd+Pt+Au, at.%	19.5	24.8	27.7	25.1

Abbreviations: nls: nielsenite; at: atokite; ch: chalcosine; sk: skaergaardite;

Table 9. Chemical composition and formula of the native (Cu,Pd)Cu alloy and (Cu,Pt)Cu alloy and skaergaardite type (Cu,Pd)sk alloy in PGM-grains of the heavy mineral concentrates of sample 90-18 1012.

Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Grain	40 gr16	40 gr16	40 gr26	40 gr30	40 gr44	40 gr59	40 gr69	40 gr74
phase	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$
Association	$(Cu,Pd)_{Cu}$zon1	$(Cu,Pd)_{Cu}$zon2	$(Cu,Pd)_{Cu}$+ ch	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$+ dg	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$+ ch	$(Cu,Pd)_{Cu}$+ ch
composition, wt%								
Pd	12.3	14.7	10.5	18.9	20.6	16.8	22.7	14.0
Pt	1.0	1.3	6.7	3.2	0.0	0.9	1.0	5.4
Au	0.0	0.0	0.0	1.2	0.0	0.9	1.5	0.0
Cu	84.9	82.7	81.6	76.1	78.4	80.7	72.9	79.6
Fe	1.0	0.7	0.8	0.6	0.4	0.9	1.2	0.5
Total	99.2	99.4	99.6	100.0	99.4	100.2	99.3	99.5
atomic proportions								
Pd	0.080	0.090	0.070	0.130	0.140	0.110	0.150	0.090
Pt	0.000	0.010	0.020	0.010	0.000	0.000	0.000	0.020
Au	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000
Cu	0.910	0.890	0.900	0.850	0.860	0.870	0.820	0.880
Fe	0.010	0.010	0.010	0.010	0.010	0.010	0.020	0.010
Pd+Pt+Au, at.%	8.3	10.0	9.0	14.3	14.0	11.4	15.4	10.9

Analysis	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Grain	40 gr96	40 gr101	40 gr103	40 gr109		80 gr4	40 gr77	40 gr88	
phase	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{Cu}$	$(Cu,Pd)_{sk}$	$(Cu,Pt)_{Cu}$	$(Cu,Pt)_{Cu}$	$(Cu,Pt)_{Cu}$
Association	$(Cu,Pd)_{Cu}$+ ch	$(Cu,Pd)_{Cu}$+ ch	$(Cu,Pd)_{Cu}$+ cb+ch	$(Cu,Pd)_{Cu}$+ ch	avr	(Cu,Pd)sk+ ch	$(Cu,Pt)_{Cu}$+ ilm	$(Cu,Pt)_{Cu}$+ ch	avr
composition, wt%									
Pd	10.9	11.7	17.8	10.5	15.1	47.8	1.0	3.7	2.4
Pt	9.4	0.0	0.0	0.0	2.4	0.0	28.6	31.9	30.3
Au	0.0	0.0	0.0	0.0	0.3	3.7	0.0	0.0	
Cu	78.2	86.5	81.0	87.9	80.9	47.6	67.9	62.8	65.4
Fe	1.3	0.9	0.6	0.7	0.8	0.4	2.5	0.6	1.6
Total	99.8	99.1	99.4	99.1	99.5	99.5	100.0	99.0	99.7
atomic proportions									
Pd	0.07	0.07	0.12	0.07	0.10	0.37	0.01	0.03	0.02
Pt	0.01	0.00	0.00	0.00	0.01	0	0.12	0.14	0.13
Au	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Cu	0.88	0.92	0.88	0.93	0.88	0.61	0.84	0.83	0.84
Fe	0.02	0.01	0.01	0.01	0.01	0.01	0.04	0.01	0.03
Pd+Pt+Au, at.%	10.4	7.3	11.7	6.9	10.8	38.5	13.0	17.0	15.0

Abreviations: (Cu,Pd)Cu: alloy; ch: chalcosine; dg: digenite; cb: cabriite; ilm: ilmenite.

Table 10. Chemical composition and formulas of different PGE-sulpides – vysotskite, unnamed (Cu,Pd)2+xS, (Pd,Cu,Pt)3S2 - in PGM-grains of the heavy concentrates, sample 90-18 1012.

Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Grain	40 gr7	40 gr12	40 gr17	40 gr28	40 gr91	63 gr2	80 gr3	125 gr2		40 gr99	40 gr99	40 gr99	40 gr99	40 gr106
Association	sk+vys +ch	sk+vys+ bn+ch	vys+ch	vys+ch	sk+vys+ ch+fspn	vys+ch	vys+sk+ (Cu,Au)? +ch	vys+sk+ ch+bn		$(Cu,Pd)_2S$+ $(Pd,Pt,Cu)_3S_2$ +dg	$(Cu,Pd)_2S$+ $(Pd,Pt,Cu)_3S_2$ +dg	$(Cu,Pd)_2S$+ $(Pd,Pt,Cu)_3S_2$ +dg	$(Cu,Pd)_2S$+ $(Pd,Pt,Cu)_3S_2$ +dg	sk+ch+ $(Cu,Pd)_3S_2$
Phase	vys	vys	vys	vys	vys	vys	vys	vys	avr	$(Cu,Pd)_{2+x}S$	$(Cu,Pd)_{2+x}S$	$(Pd,Pt)_2(Cu,Fe)S_2$	$(Pd,Pt)_2(Cu,Fe)S_2$	$(Cu,Pd)_3S_2$
Pd	76.3	71.8	73.3	73.3	76.8	75.3	74.3	73.2	74.3	10.6	11.5	37.4	42.0	43.1
Pt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		3.0	2.2	31.2	31.0	0.00
Au	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	1.7	0.0	0.0
Cu	0.0	2.4	2.4	3.6	0.0	1.2	1.8	1.6	1.6	69.2	68.2	10.6	7.1	35.6
Fe	0.0	1.2	0.7	0.0	0.0	0.4	0.0	0.0	0.3	1.2	1.5	2.9	3.0	0.8
Ni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.1	0.0	0.0	0.0	0.0	0.0
S	22.8	23.6	23.5	23.6	23.2	23.7	23.5	23.5	23.4	16.3	16.2	15.8	17.1	20.2
sum	99.1	99.0	100.6	100.5	100.0	100.6	99.6	99.1	99.7	100.3	99.6	99.6	100.2	99.7
Pd	1.00	0.92	0.93	0.93	1.00	0.96	0.96	0.94	0.96	0.17	0.19	1.43	1.58	1.26
Pt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.03	0.02	0.65	0.63	0.00
Au	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.04	0.00	0.00
Cu	0.00	0.05	0.05	0.08	0.00	0.03	0.04	0.03	0.04	1.88	1.87	0.68	0.45	1.74
Fe	0.00	0.03	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.04	0.05	0.21	0.21	0.04
Ni	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	0.00
S	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	0.88	0.88	2.00	2.13	1.96
sum	2.00	2.00	1.99	2.00	2.00	2.00	2.00	1.99	2.00	3.00	3.01	5.01	5.00	5.00

abbreviations: sk: skaergaardite; vys: vysotskite; ch: chalcosine; bn: bornite; fspn: ferrosaponite; (cu,Au)?: alloy; dg: digenite; $(Cu,Pd)_2S$: unnamed mineral; $(Pd,Pt,Cu)_3S_2$: unnamed mineral; $(Pd,Pt)_2(Cu,Fe)S_2$: unnamed mineral; $(Cu,Pd)_3S_2$: unnamed mineral

Table 11 **Chemical composition and formula of (Pd,Cu,Pb) alloy, cabriite and keithconnite in PGM-grains of heavy mineral concentrates, sample 90-18 1012**

Analysis	**1**	**2**	**3**
Grain	40 gr45	40 gr103	125 gr1
Association	(Pd,Pb,Cu) +ch	cb+ch+ $(Cu,Pd)_{Cu}$	kth+ch
Phase	(Pd,Pb,Cu)	cb	kth
Composition (wt%)			
Pd	82.70	52.40	63.60
Pt	1.50	0.00	0.00
Cu	2.00	16.60	5.00
Fe	1.00	0.80	0.00
Sn	0.40	29.90	0.00
Te	0.00	0.00	30.10
Pb	12.30	0.00	1.40
Total	99.90	99.70	100.10
Atomic proportions			
Pd	0.87	1.93	2.60
Pt	0.01	0.00	0.00
Cu	0.04	1.02	0.34
Fe	0.02	0.06	0.00
Sn	0.00	0.99	0.00
Te	0.00	0.00	1.03
Pb	0.07	0.00	0.03
Total	1.00	4.00	4.00

abbreviations: (Pd,Pb,Cu): alloy; $(Cu,Pd)_{Cu}$: alloy; cb: cabriite; ch: chalcosine; kth: keithconnite.

PLATES

Plate 1

Relationship between rock-forming minerals, Fe-Ti oxides, sulphides and PGM in sample 90-18 1012; polished sample, SEM-image (BIE). Abbreviations: Pl: plagioclase; pyr (exs): pyroxene exsolution texture; ilm: ilmenite; timt: titanomagnetite; ol: olivine, bn: bornite; sk: skaergaardite. Image 5 is part of image 4 at 4 times magnification.

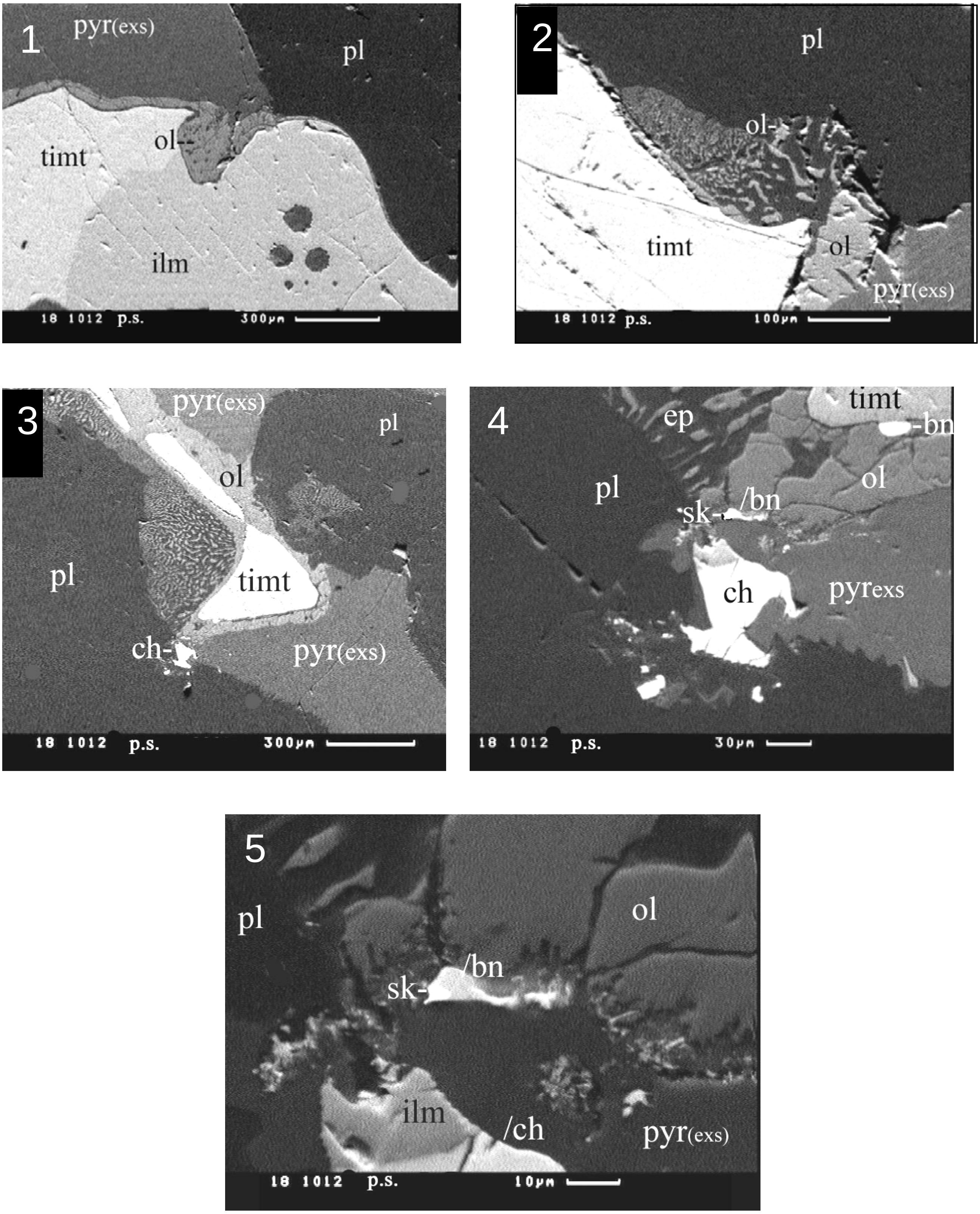

1
pyr(exs)
pl
ol-
timt
ilm
18 1012 p.s.
300μm
2
pl
ol-
timt
ol
pyr(exs)
18 1012 p.s.
100μm
3
pyr(exs)
pl
ol
pl
timt
ch-
pyr(exs)
18 1012 p.s.
300μm
4
ep
timt
-bn
pl
ol
sk-
/bn
ch
pyrexs
18 1012 p.s.
30μm
5
pl
ol
/bn
sk-
ilm
/ch
pyr(exs)
18 1012 p.s.
10μm

Plate 2

Polished samples of the heavy mineral HS-concentrates from sample 90-18 1012. 1) 80-125µm fraction; 2) 63-80µm fraction; 3) <40µm fraction), SEM-images (BIE) Abbreviations: ilm) ilmenite; sk) skaergaardite; nls: nielsenite; vys: vysotskite; bn: bornit; ch: chalcosine and cpx: clinopyroxenes.

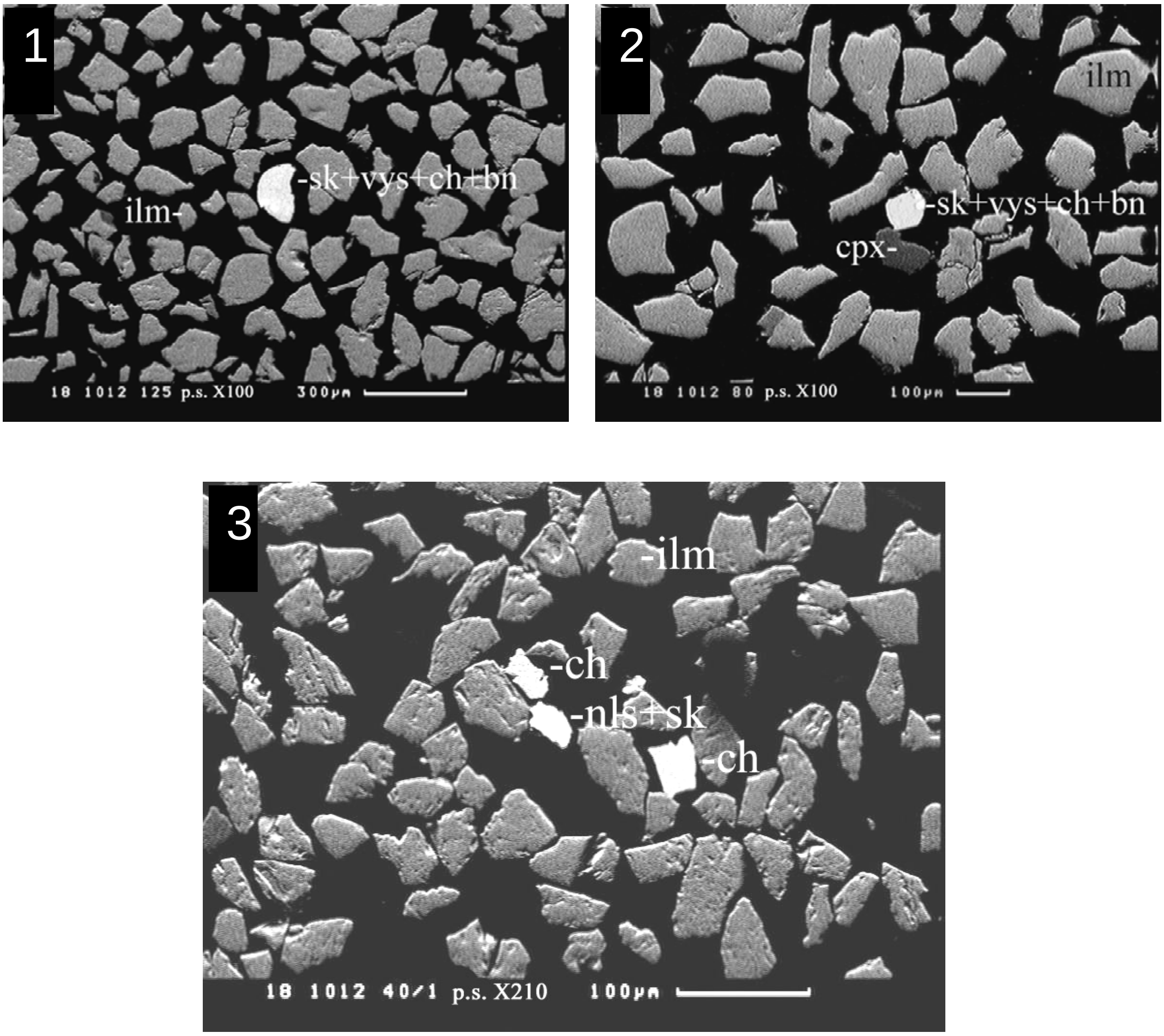

1
-sk+vys+ch+bn
ilm-
18 1012 125 p.s. X100 300μm
2
ilm
-sk+vys+ch+bn
cpx-
18 1012 80 p.s. X100 100μm
3
-ilm
-ch
-nls+sk
-ch
18 1012 40/1 p.s. X210 100μm

Plate 3

Baddeleyite grain (e.g.,for age dating) in the heavy mineral HS-concentrate of sample 90-18 1012; polished sample, SEM-image (BIE). Abbreviations: bdl: baddeleyite and ilm: ilmenite.

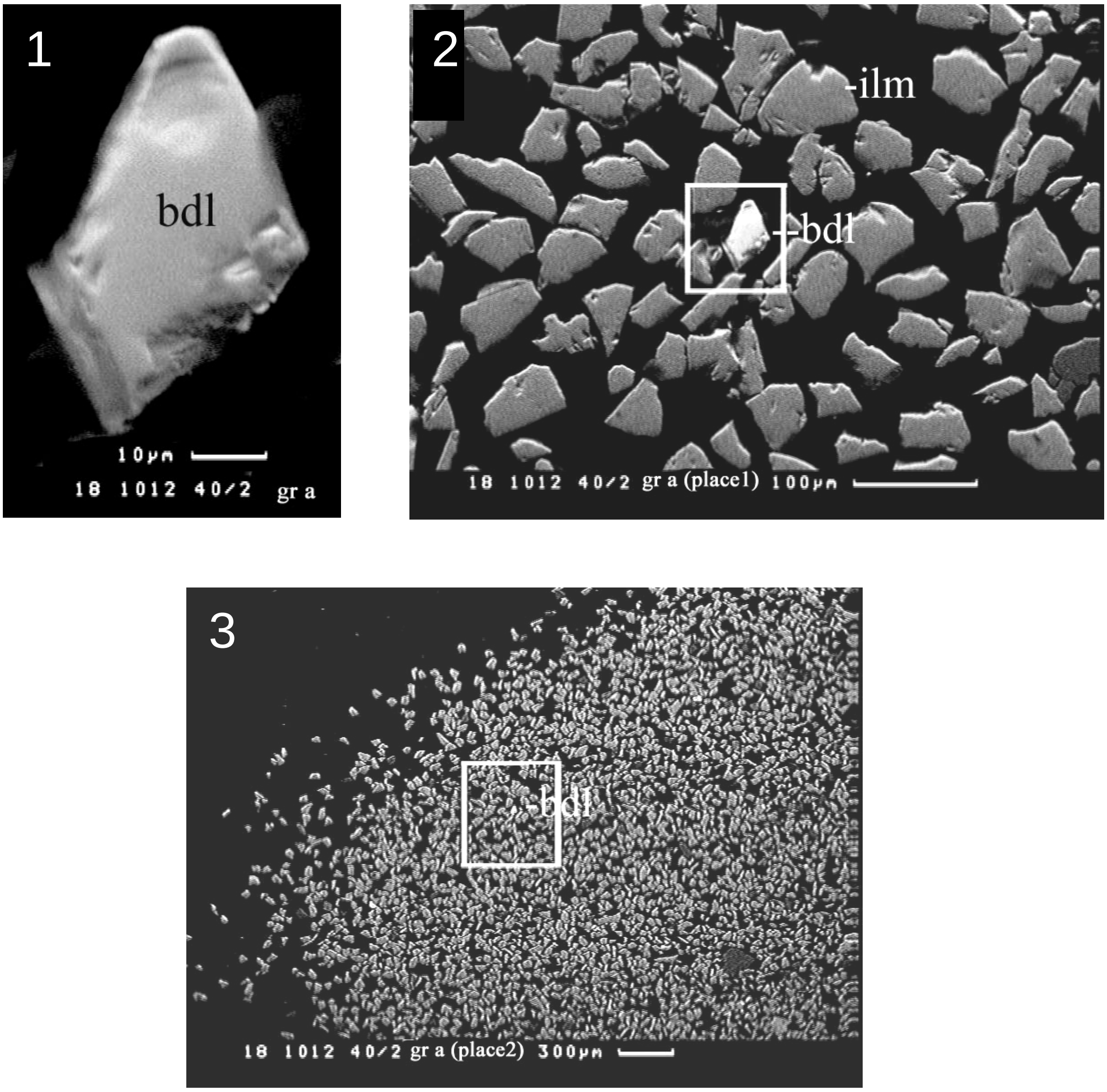
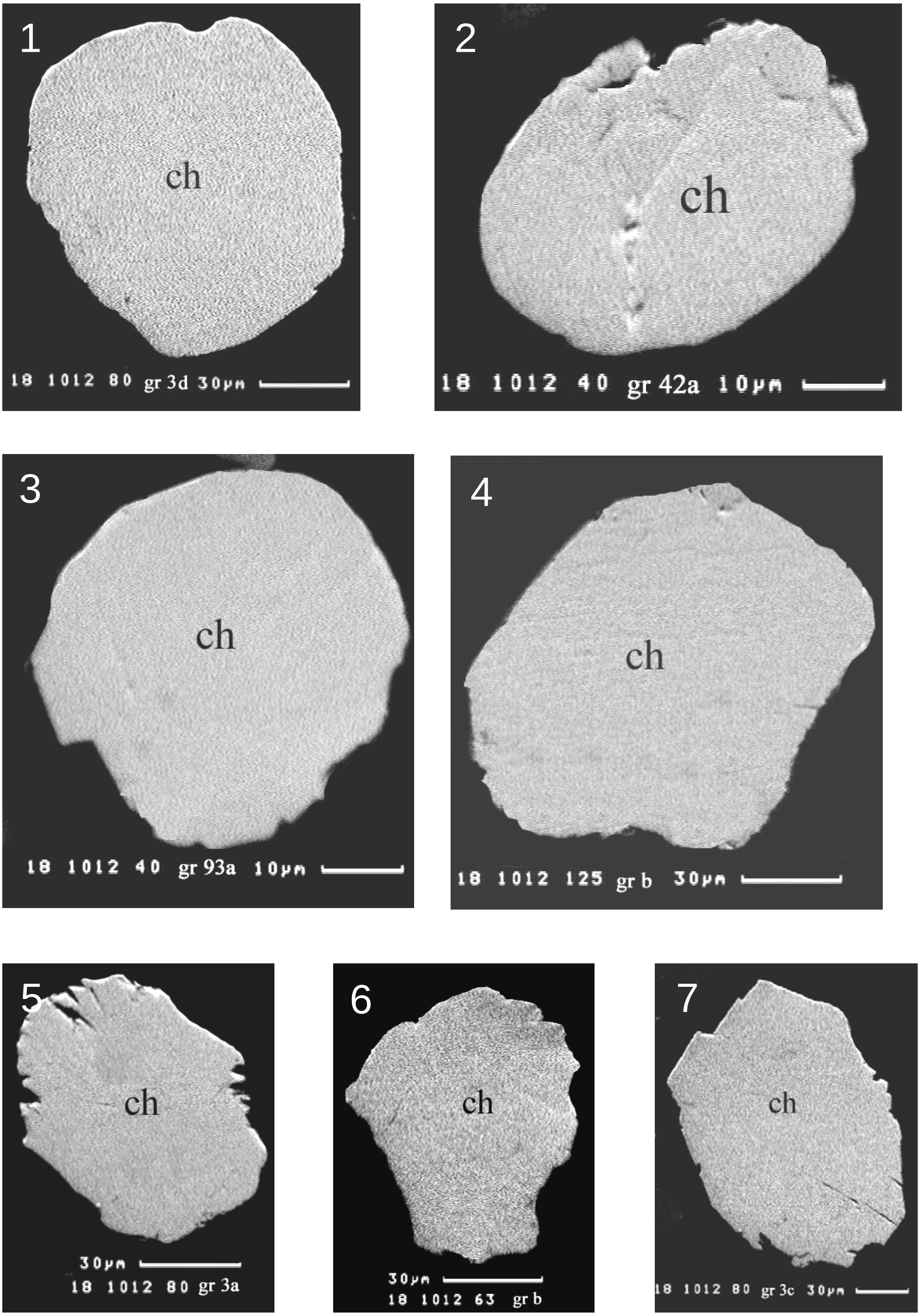
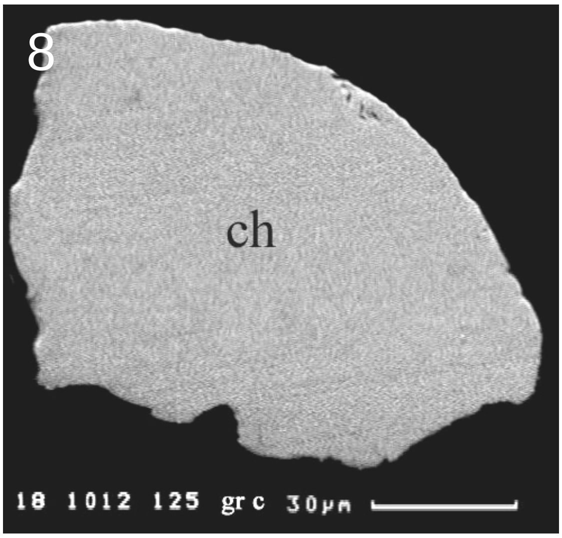
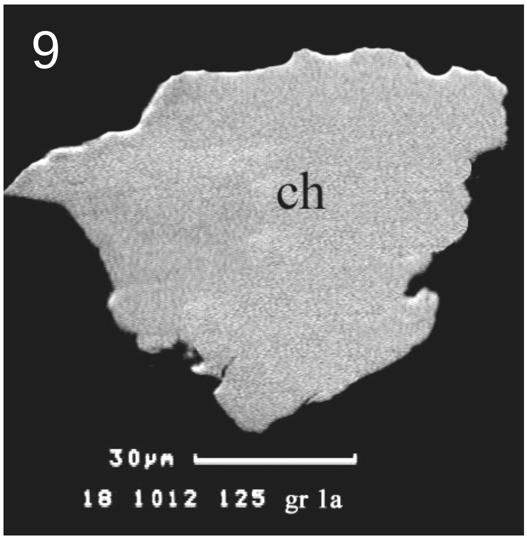

1
bdl
10μm
18 1012 40/2 gr a
2
-ilm
-bdl
18 1012 40/2 gr a (place1) 100μm
3
-bdl
18 1012 40/2 gr a (place2) 300μm

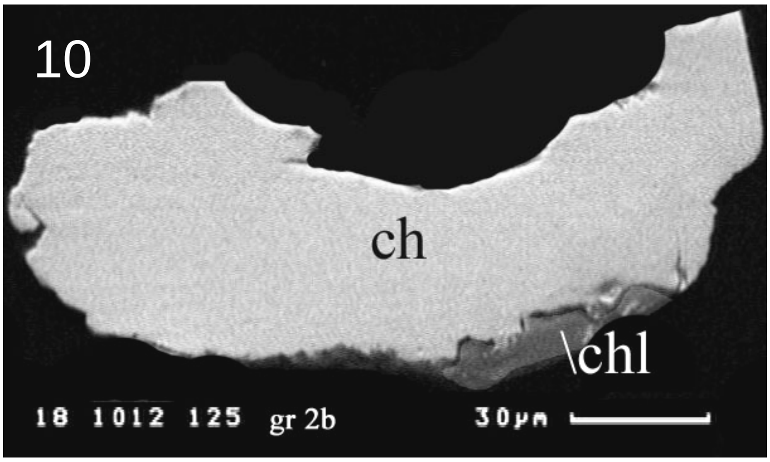
Plate 4

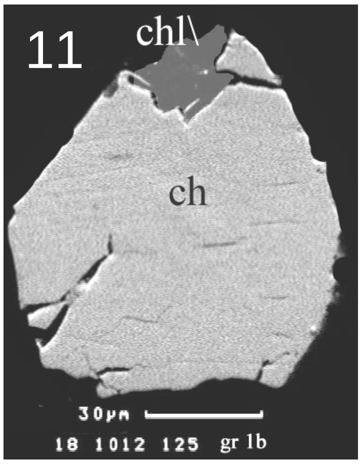
Globules and irregular grains of sulphide in the sample 90-18 1012; polished samples of heavy mineral HS-concentrates; SEM-image (BIE). Abbreviations: bn: bornite; ch: chalcosin; ch: chlorite; mt: magnetite and ap: apatite.

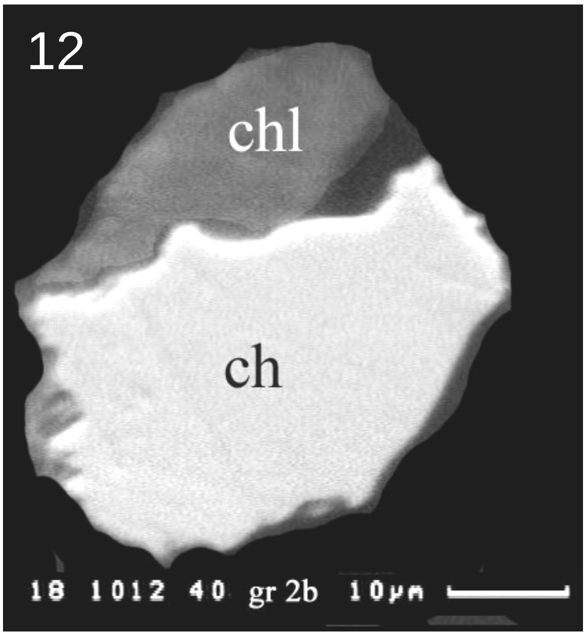

1
ch
18 1012 80 gr 3d 30μm
2
ch
18 1012 40 gr 42a 10μm
3
ch
18 1012 40 gr 93a 10μm
4
ch
18 1012 125 gr b 30μm
5
ch
30μm
18 1012 80 gr 3a
6
ch
30μm
18 1012 63 gr b
7
ch
18 1012 80 gr 3c 30μm

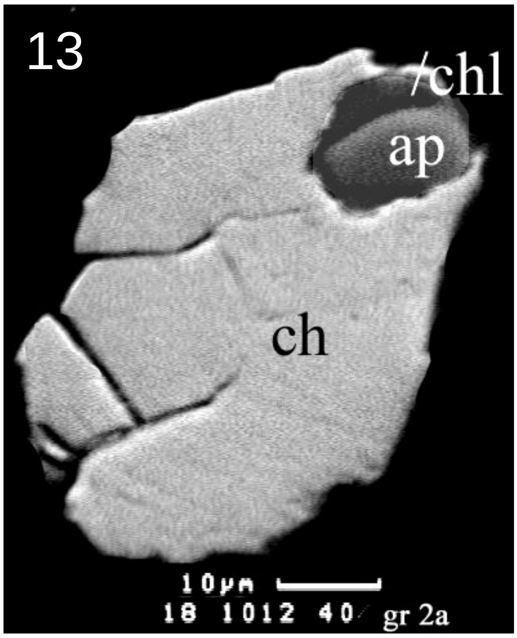

8
ch
18 1012 125 gr c 30μm

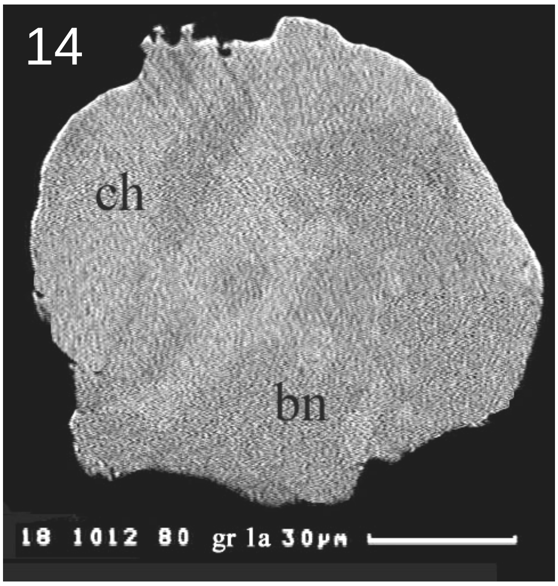

9
ch
30μm
18 1012 125 gr 1a

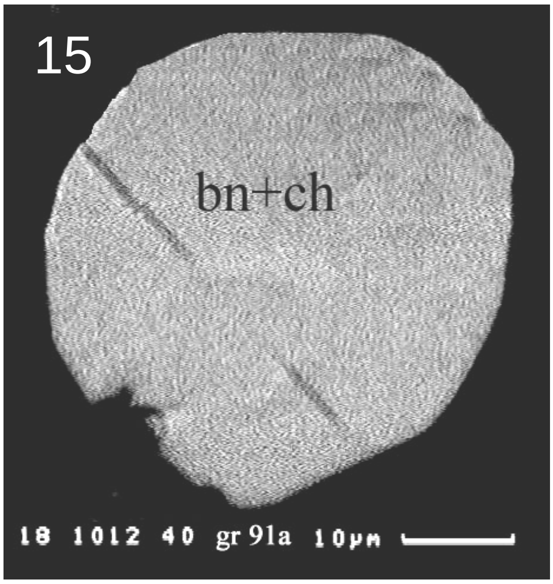

10
ch
\chl
18 1012 125 gr 2b
30μm

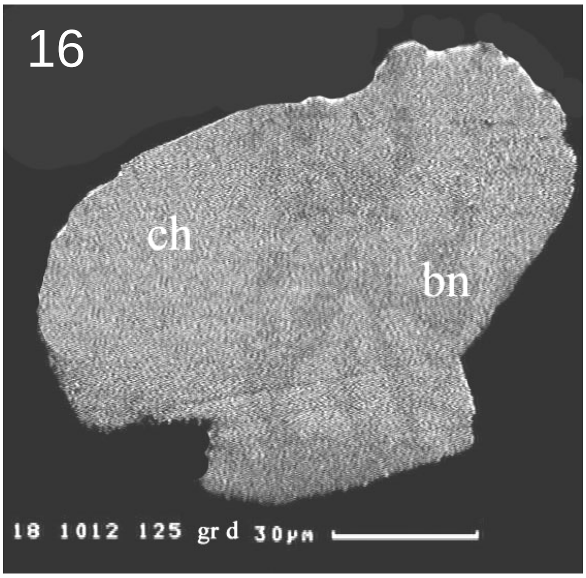

11
chl\
ch
30μm
18 1012 125 gr 1b

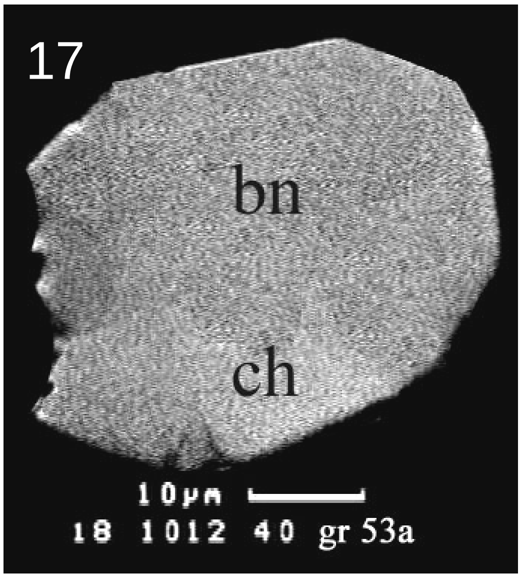

12
chl
ch
18 1012 40 gr 2b 10μm

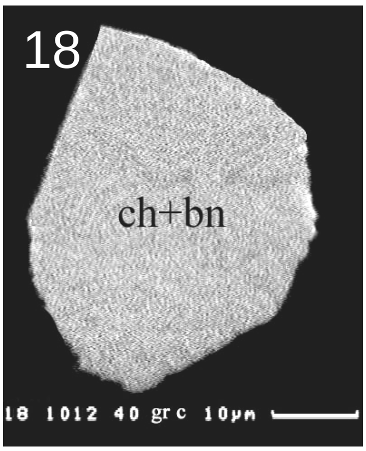

13
/chl
ap
ch
10μm
18 1012 40 gr 2a

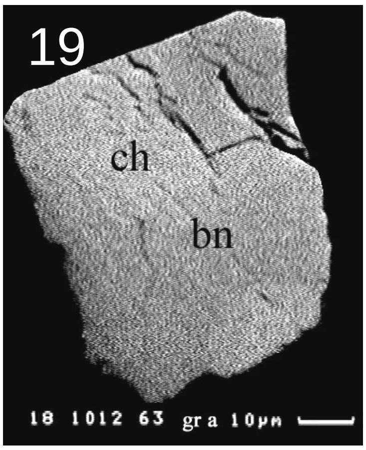

14
ch
bn
18 1012 80 gr 1a 30μm

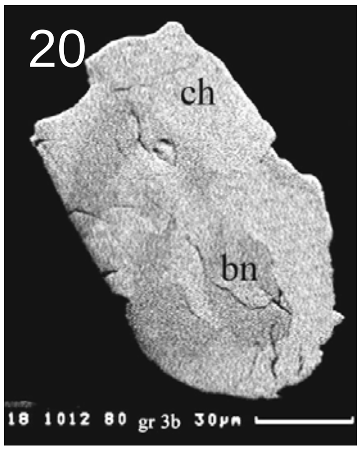

15
bn+ch
18 1012 40 gr 91a 10μm


16
ch
bn
18 1012 125 gr d 30μm


17
bn
ch
10μm
18 1012 40 gr 53a


18
ch+bn
18 1012 40 gr c 10μm


19
ch
bn
18 1012 63 gr a 10μm


20
ch
bn
18 1012 80 gr 3b 30μm

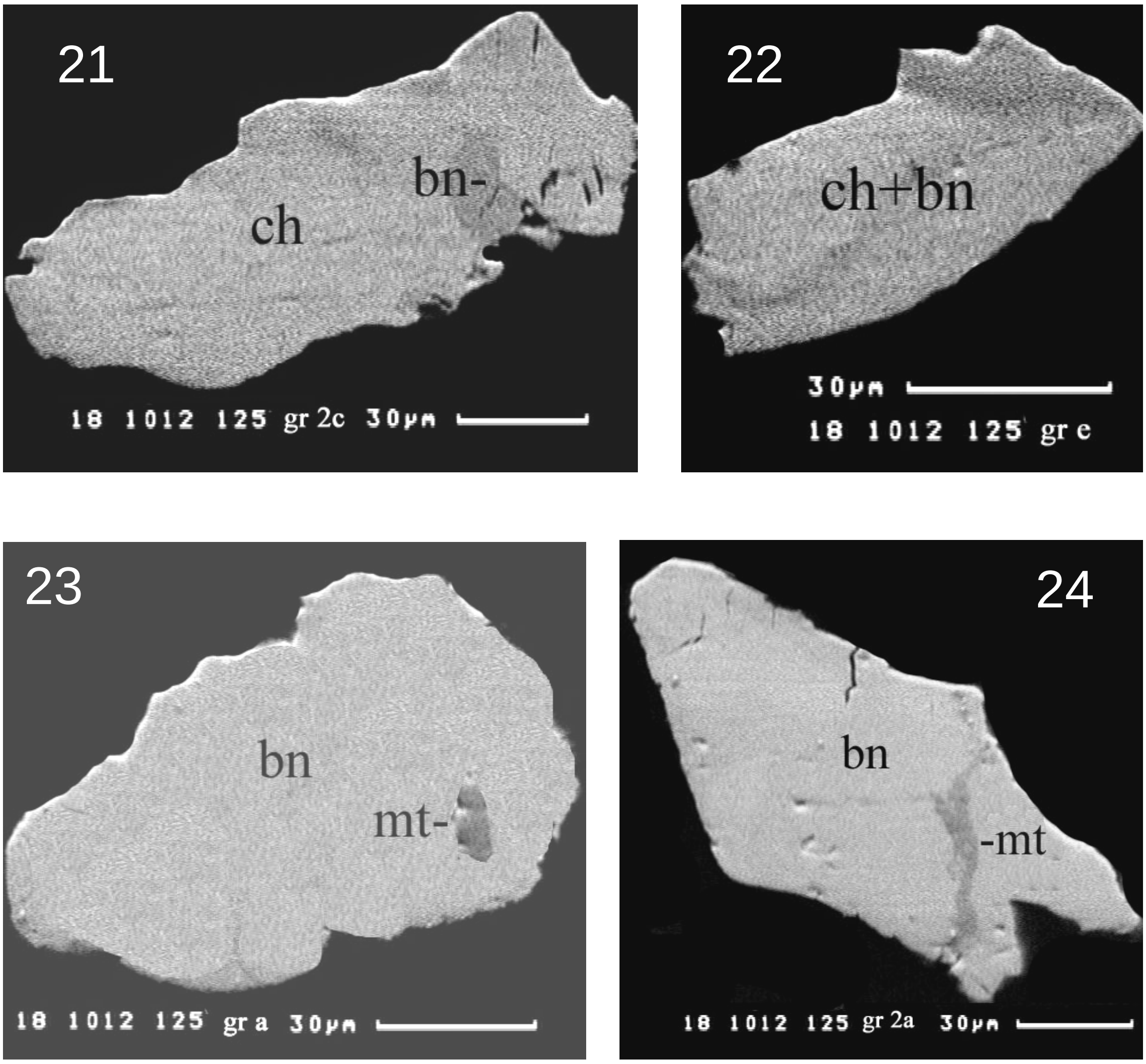
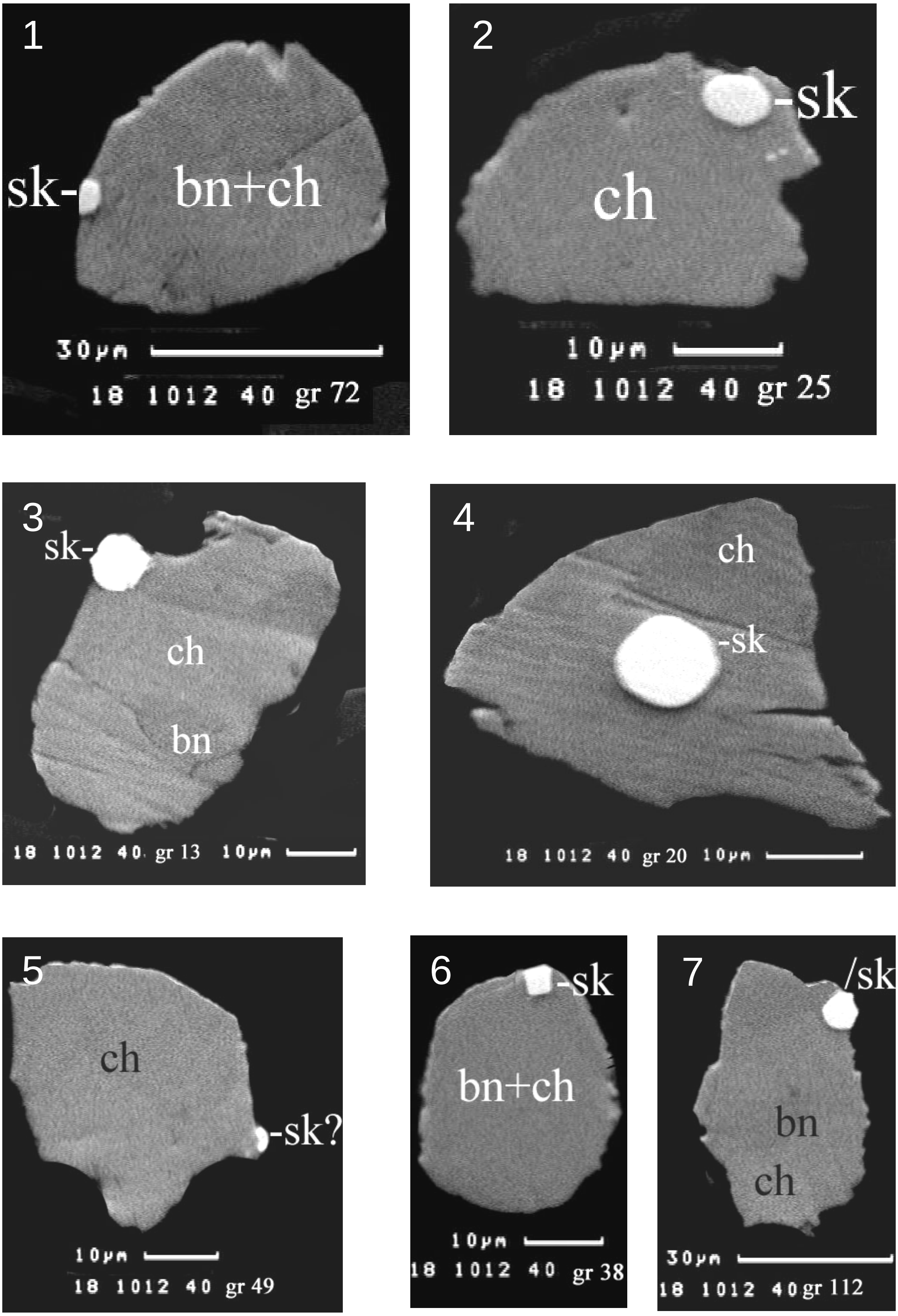
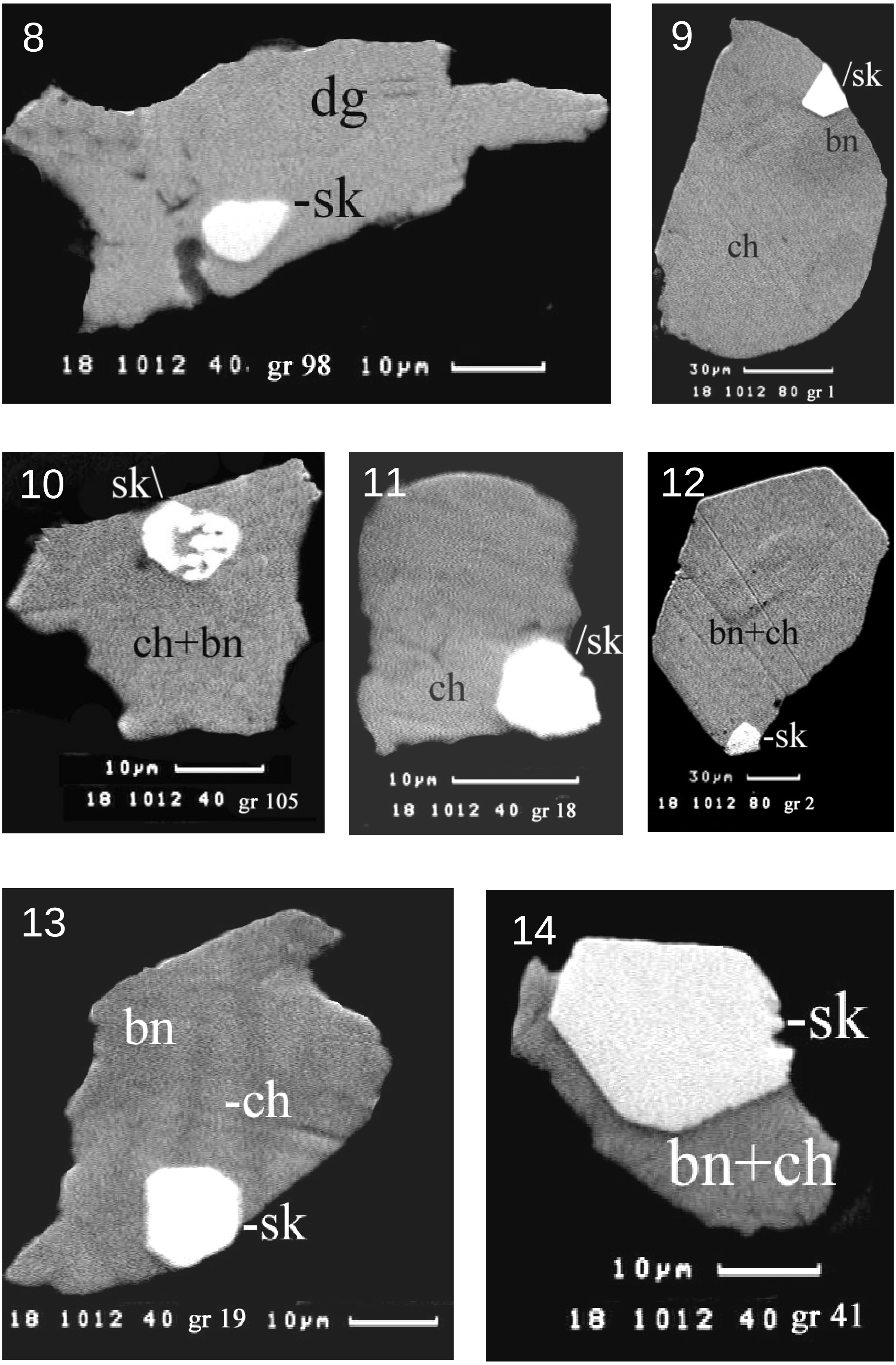
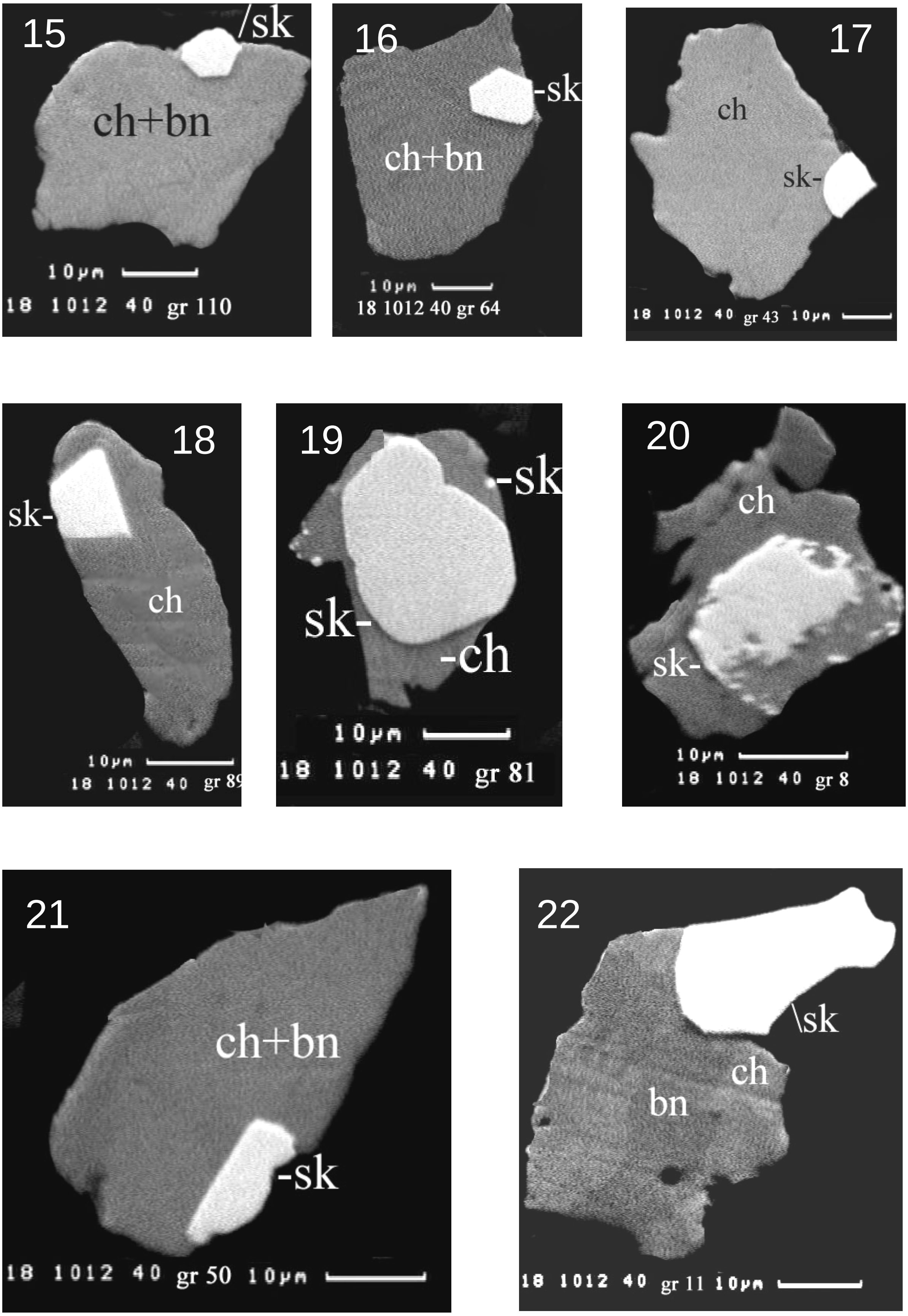

21
bn-
ch
18 1012 125 gr 2c 30μm
22
ch+bn
30μm
18 1012 125 gr e
23
bn
mt-
18 1012 125 gr a 30μm
24
bn
-mt
18 1012 125 gr 2a 30μm

Plate 5

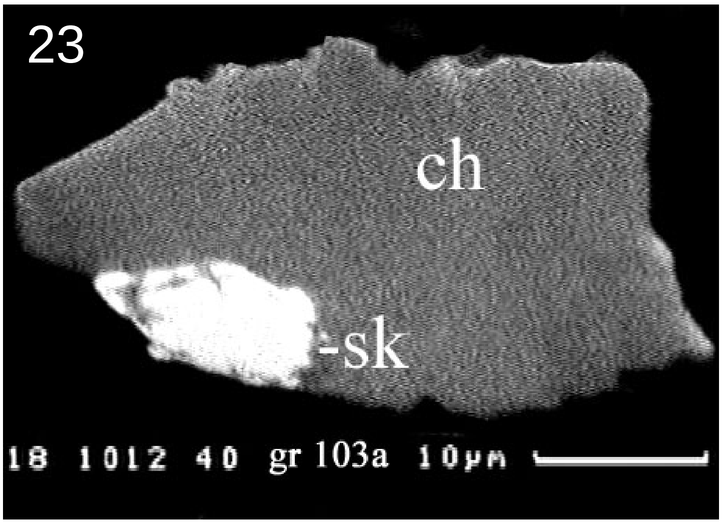
Globules and grains of sulphide with inclusions of skaergaardite (**bms**), skaergaardite particles attached base metal sulphides (**bms-L**), skaergaardite particles attached base metal sulphides and gangue (**sag**) and skaergaardite attached gangue (**ag**) in heavy mineral HS-concentrates of sample 90-18 1012; polished samples, SEM-image (BIE). Abbreviations: sk: skaergaardite; bn: bornite; ch: chalcosine; dg: digenite; ilm: ilmenite; cpx: clinopyroxene; serp: serpentine; chl: chlorite and fspn: ferrosaponite.

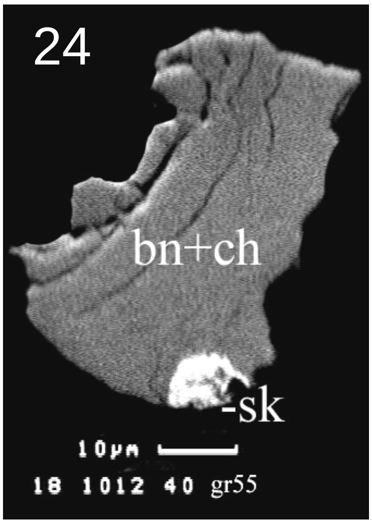

1
sk-
bn+ch
30μm
18 1012 40 gr 72
2
-sk
ch
10μm
18 1012 40 gr 25
3
sk-
ch
bn
18 1012 40. gr 13 10μm
4
ch
-sk
18 1012 40 gr 20 10μm
5
ch
-sk?
10μm
18 1012 40 gr 49
6
-sk
bn+ch
10μm
18 1012 40 gr 38
7
/sk
bn
ch
30μm
18 1012 40 gr 112

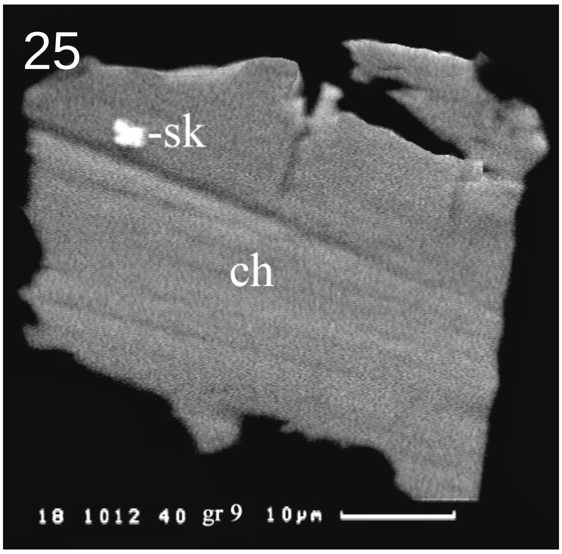

8
dg
-sk
18 1012 40 gr 98 10μm
9
/sk
bn
ch
30μm
18 1012 80 gr 1
10
sk\
ch+bn
10μm
18 1012 40 gr 105
11
/sk
ch
10μm
18 1012 40 gr 18
12
bn+ch
-sk
30μm
18 1012 80 gr 2
13
bn
-ch
-sk
18 1012 40 gr 19 10μm
14
-sk
bn+ch
10μm
18 1012 40 gr 41

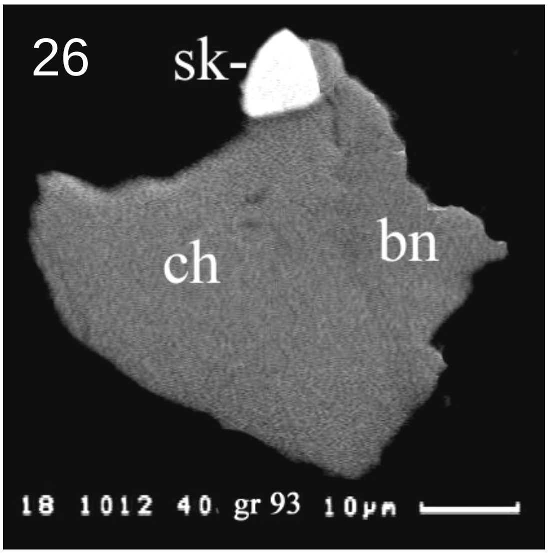


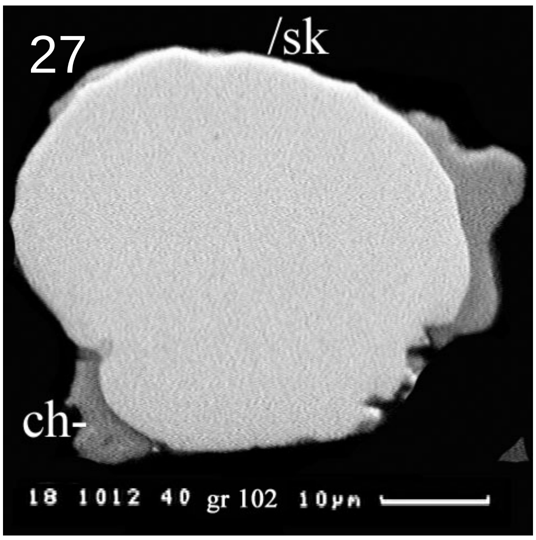
15
/sk
ch+bn
10μm
18 1012 40 gr 110
16
-sk
ch+bn
10μm
18 1012 40 gr 64
17
ch
sk-
18 1012 40 gr 43 10μm
18
sk-
ch
10μm
18 1012 40 gr 8
19
-sk
sk-
-ch
10μm
18 1012 40 gr 81
20
ch
sk-
10μm
18 1012 40 gr 8
21
ch+bn
-sk
18 1012 40 gr 50 10μm
22
\sk
ch
bn
18 1012 40 gr 11 10μm

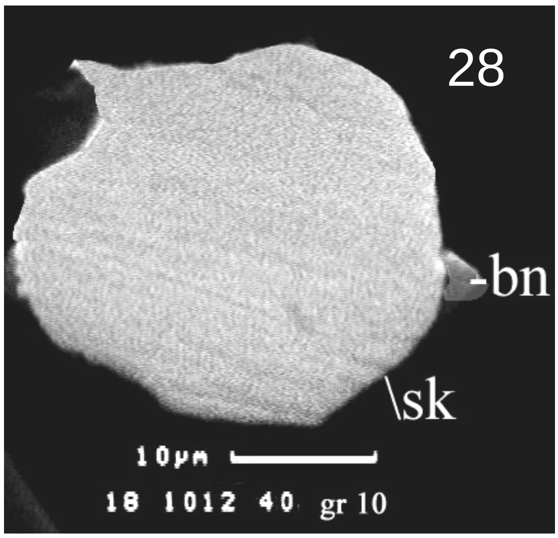

23
ch
-sk
18 1012 40 gr 103a 10µm

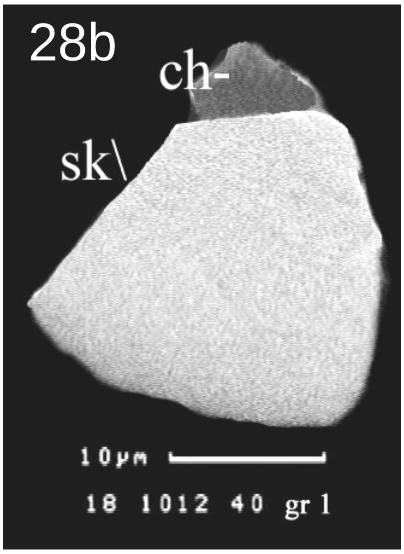

24
bn+ch
-sk
10µm
18 1012 40 gr55

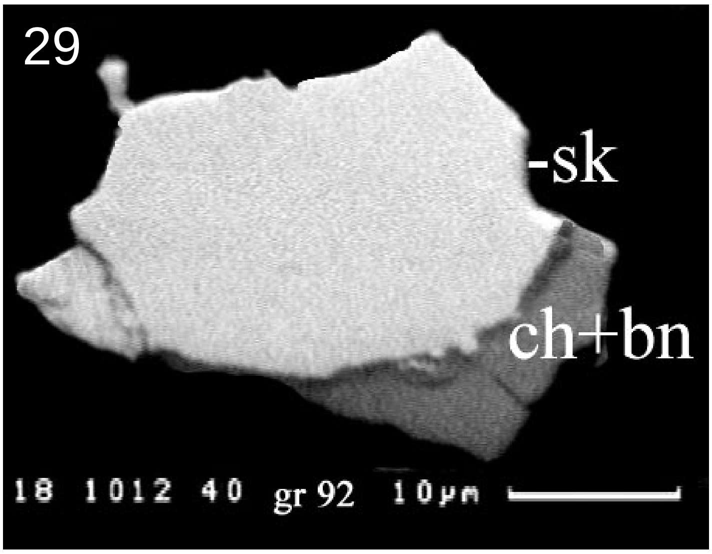

25
-sk
ch
18 1012 40 gr 9 10µm

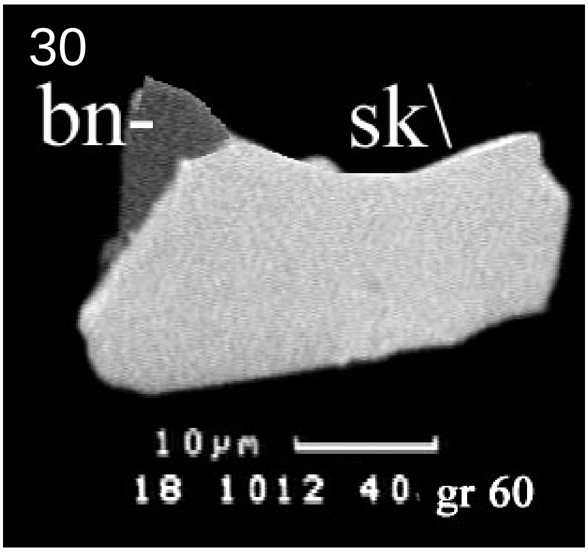

26
sk-
ch
bn
18 1012 40 gr 93 10µm

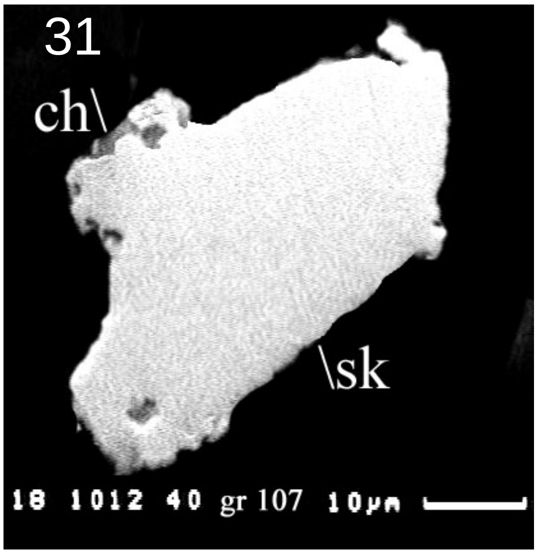

27
/sk
ch-
18 1012 40 gr 102 10µm

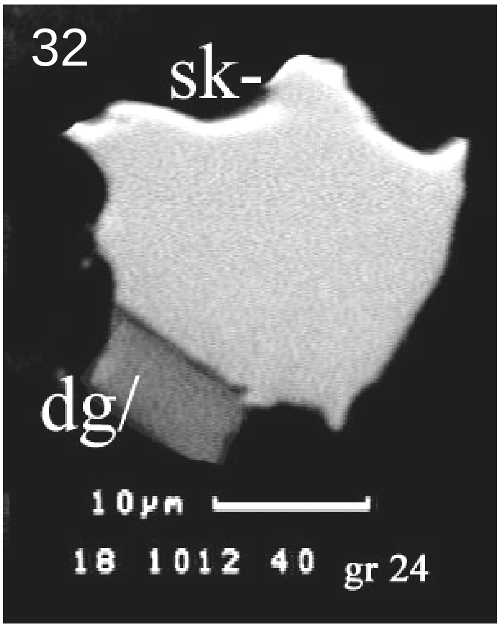

28
-bn
\sk
10µm
18 1012 40 gr 10

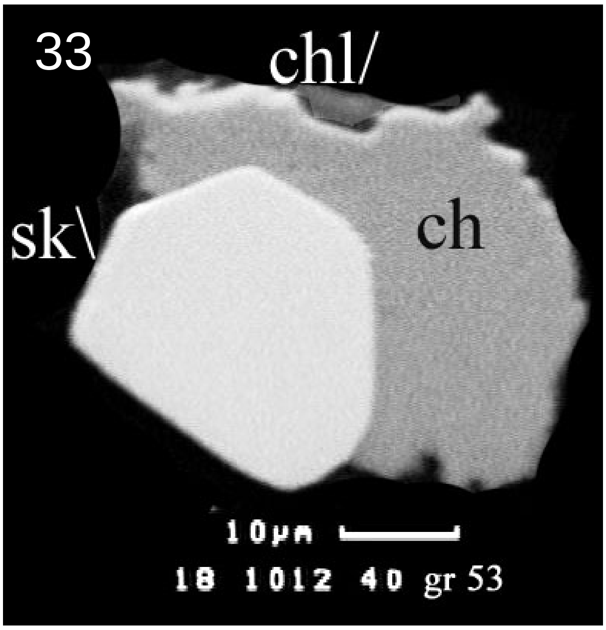

28b
ch-
sk\
10μm
18 1012 40 gr 1

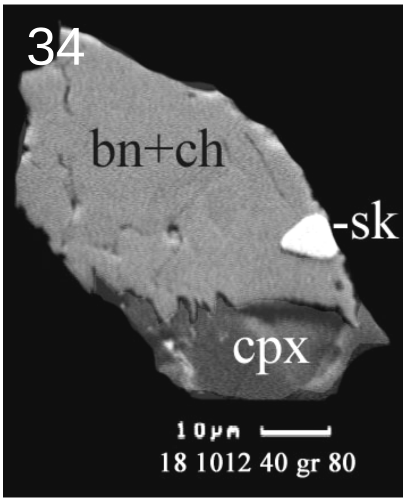

29
-sk
ch+bn
18 1012 40 gr 92 10μm

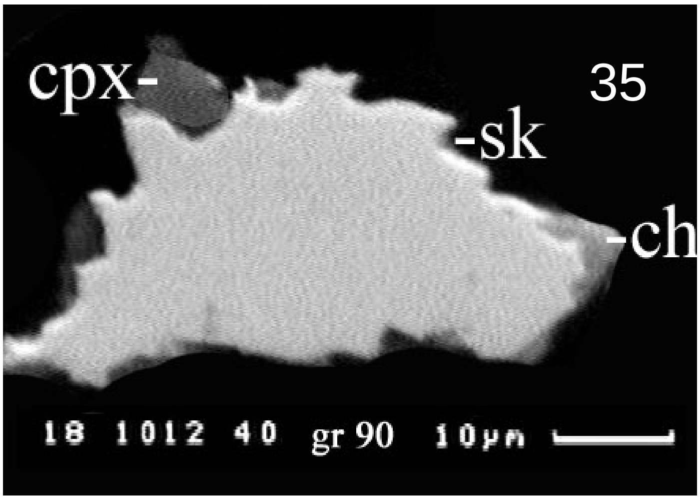

30
bn-
sk\
10μm
18 1012 40 gr 60

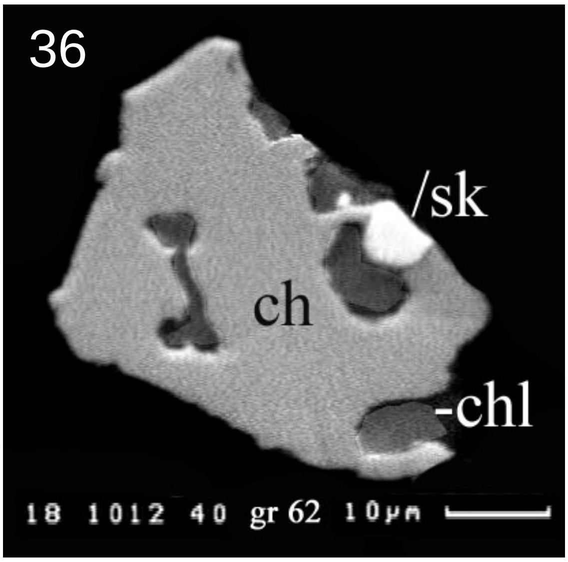

31
ch\
\sk
18 1012 40 gr 107 10μm

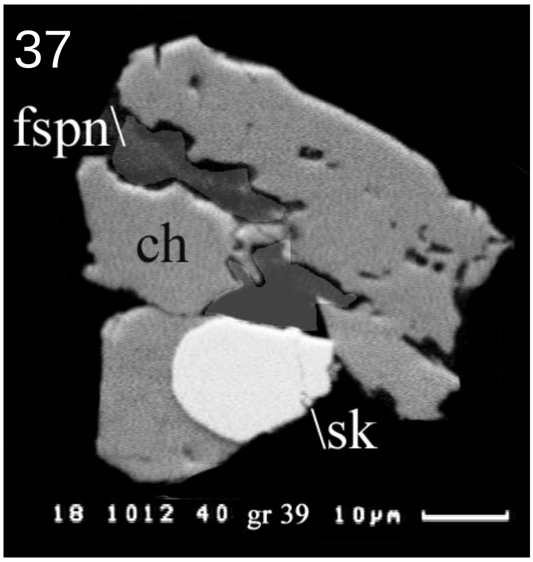

32
sk-
dg/
10μm
18 1012 40 gr 24

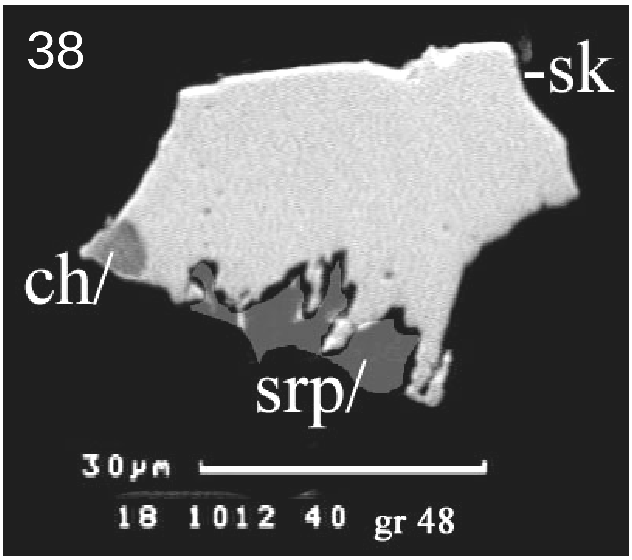

33
chl/
sk\
ch
10μm
18 1012 40 gr 53

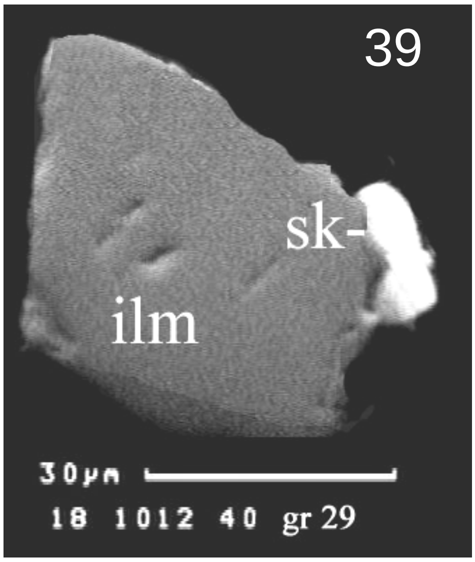

34
bn+ch
-sk
cpx
10µm
18 1012 40 gr 80

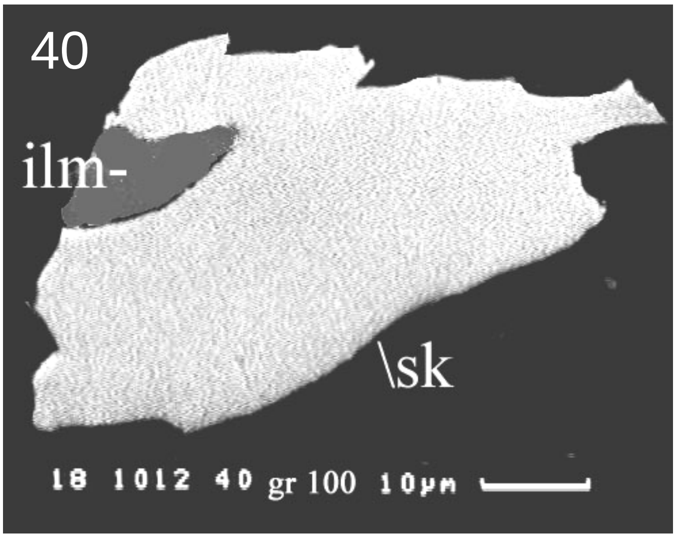

cpx-
35
-sk
-ch
18 1012 40 gr 90 10µm

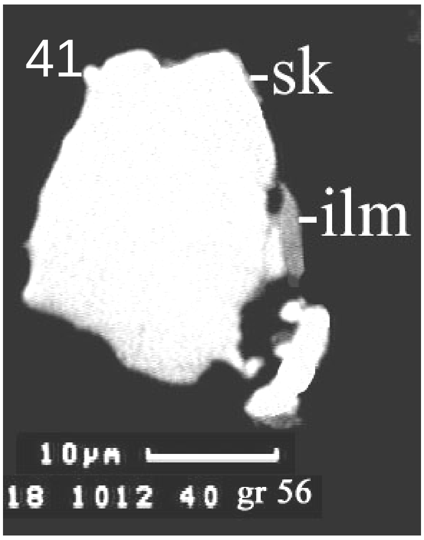

36
/sk
ch
-chl
18 1012 40 gr 62 10µm

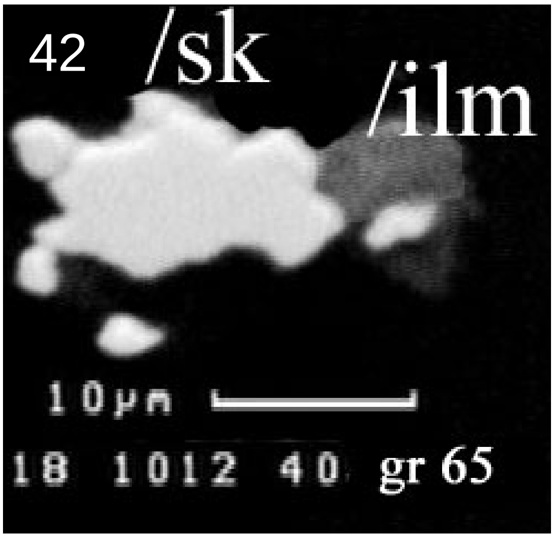

37
fspn\
ch
\sk
18 1012 40 gr 39 10µm


38
-sk
ch/
srp/
30µm
18 1012 40 gr 48


39
sk-
ilm
30µm
18 1012 40 gr 29


40
ilm-
\sk
18 1012 40 gr 100 10μm


41
-sk
-ilm
10μm
18 1012 40 gr 56


42
/sk
/ilm
10μm
18 1012 40 gr 65

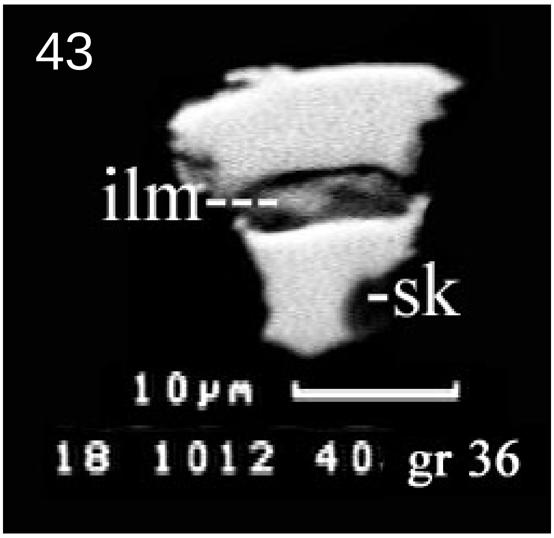
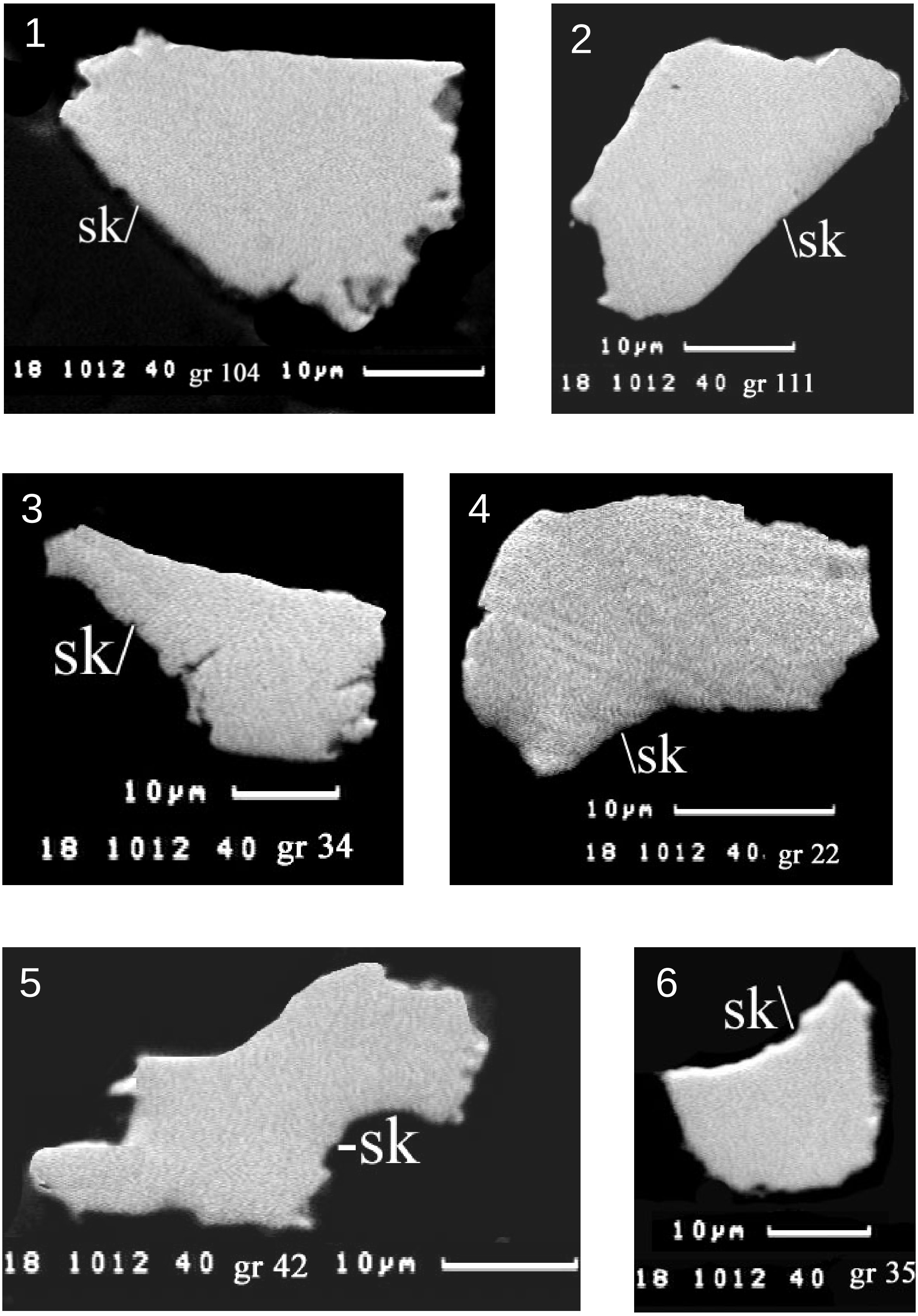
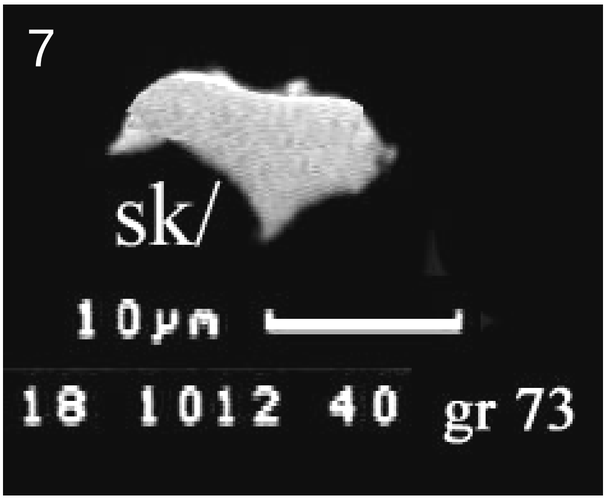
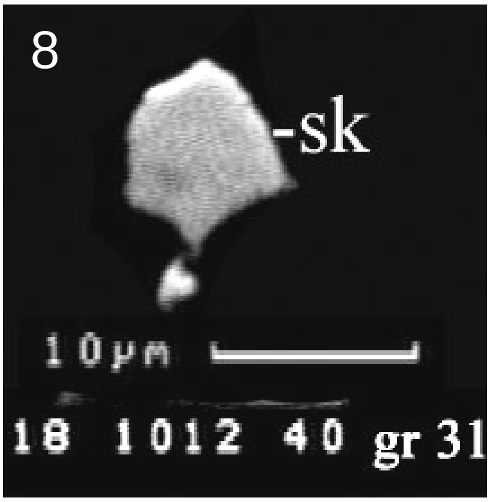

43
ilm---
-sk
10μm
18 1012 40 gr 36

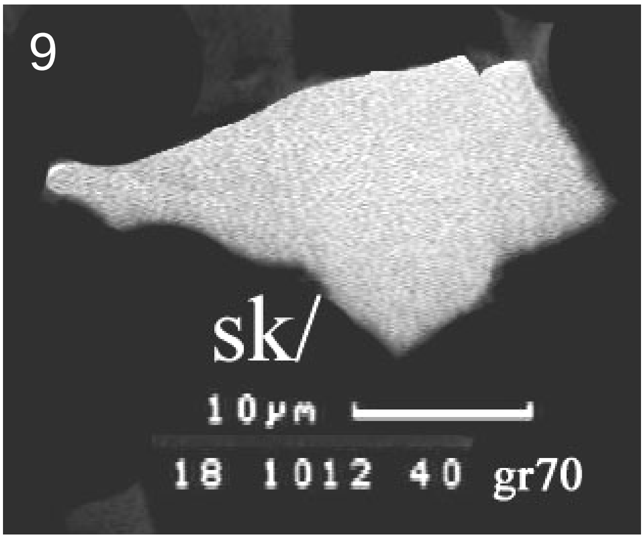
Plate 6

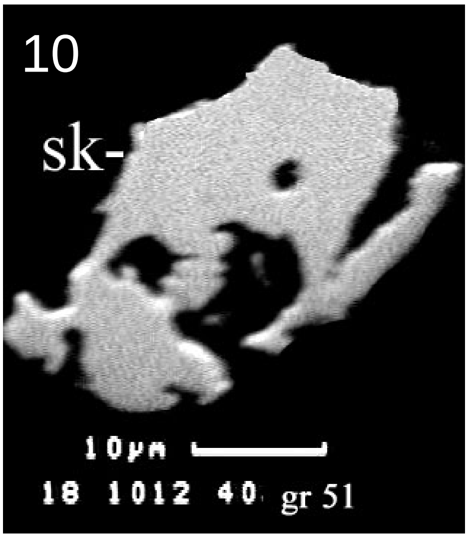
Liberated grains of skaergaardite in the heavy mineral HS-concentrates of the sample 90-18 1012, polished samples, SEM-image (BIE). Abbreviation: sk: skaergaardite.

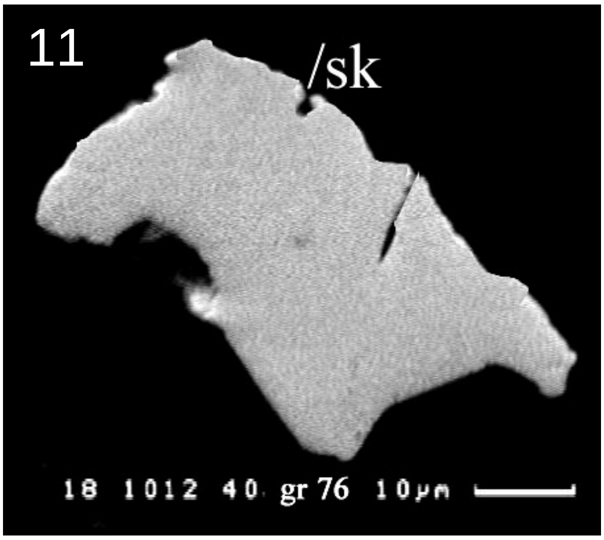

1
sk/
18 1012 40 gr 104 10μm
2
\sk
10μm
18 1012 40 gr 111
3
sk/
10μm
18 1012 40 gr 34
4
\sk
10μm
18 1012 40 gr 22
5
-sk
18 1012 40 gr 42 10μm
6
sk\
10μm
18 1012 40 gr 35

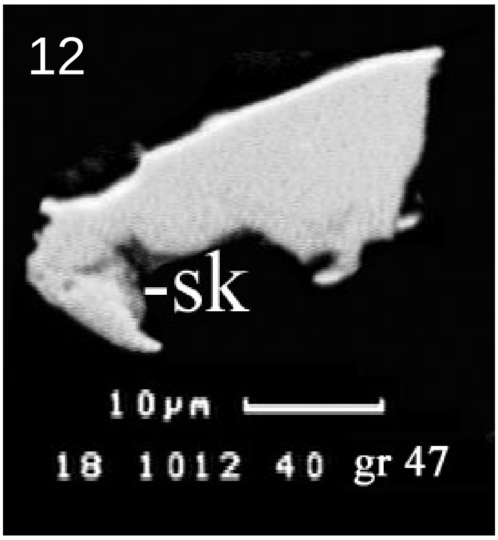

7
sk/
10μm
18 1012 40 gr 73

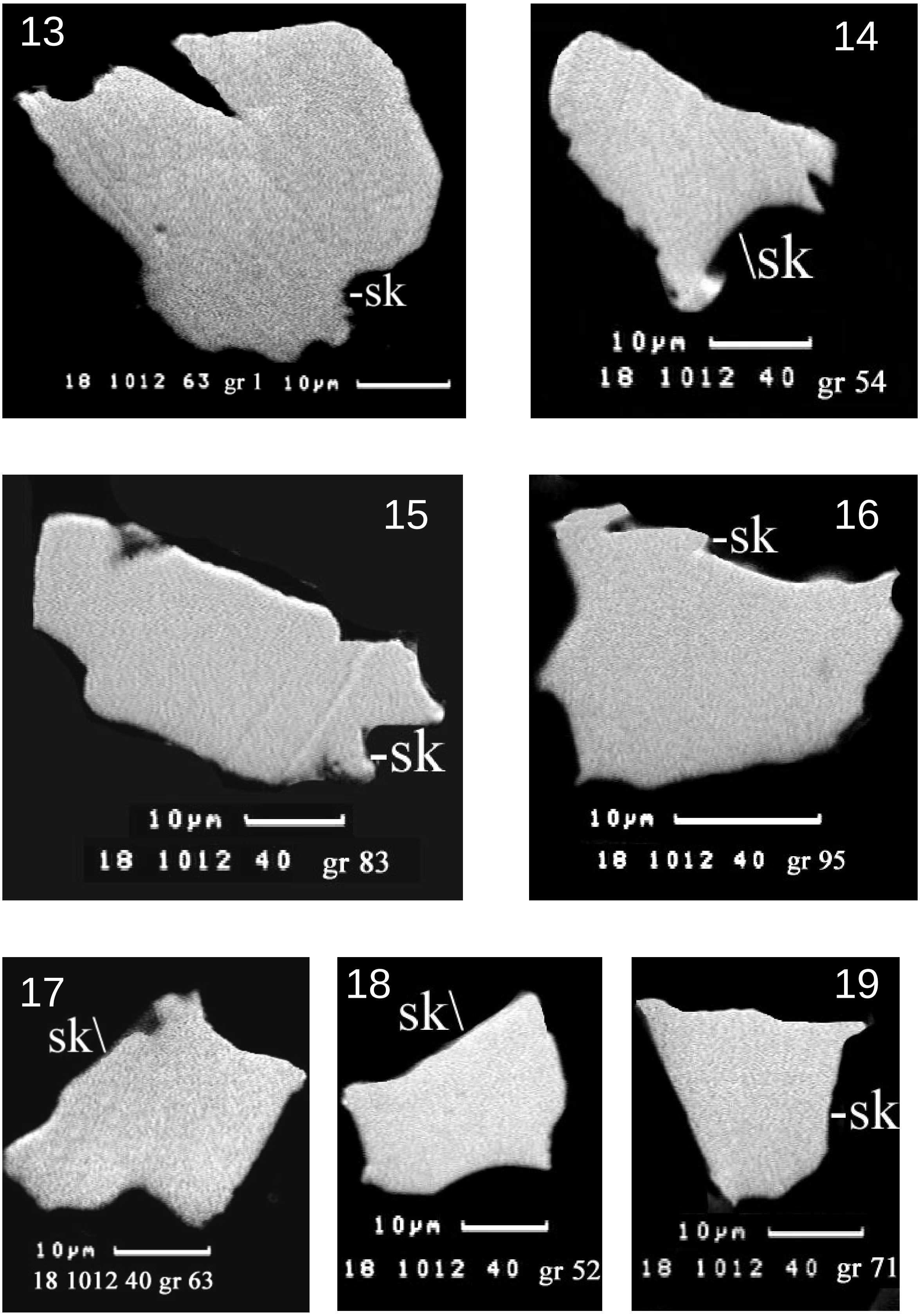

8
-sk
10μm
18 1012 40 gr 31

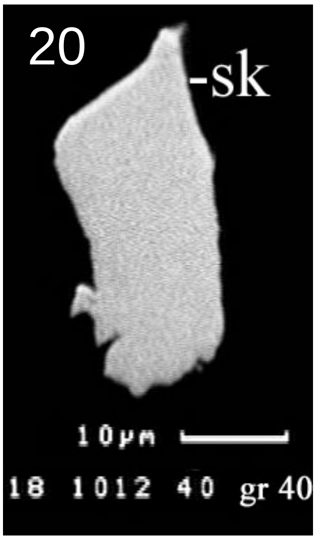

9
sk/
10μm
18 1012 40 gr70

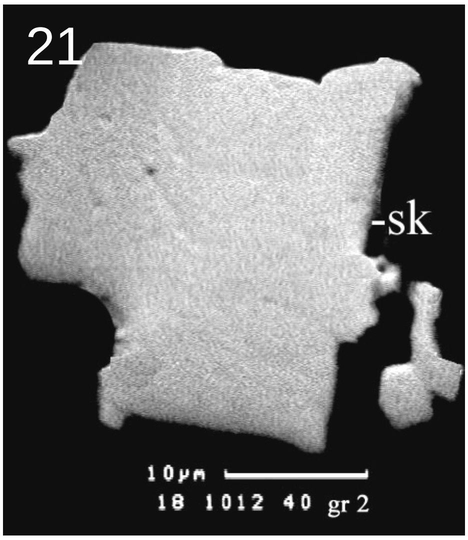

10
sk-
10μm
18 1012 40 gr 51

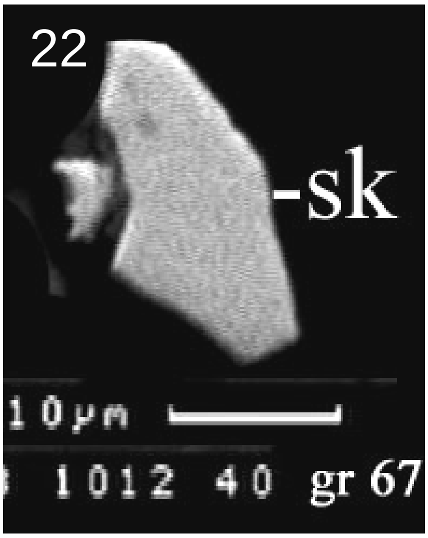

11
/sk
18 1012 40 gr 76 10μm


12
-sk
10μm
18 1012 40 gr 47


13
-sk
18 1012 63 gr 1 10μm
14
\sk
10μm
18 1012 40 gr 54
15
-sk
10μm
18 1012 40 gr 83
16
-sk
10μm
18 1012 40 gr 95
17
sk\
10μm
18 1012 40 gr 63
18
sk\
10μm
18 1012 40 gr 52
19
-sk
10μm
18 1012 40 gr 71


20
-sk
10μm
18 1012 40 gr 40


21
-sk
10μm
18 1012 40 gr 2


22
-sk
10μm
1012 40 gr 67

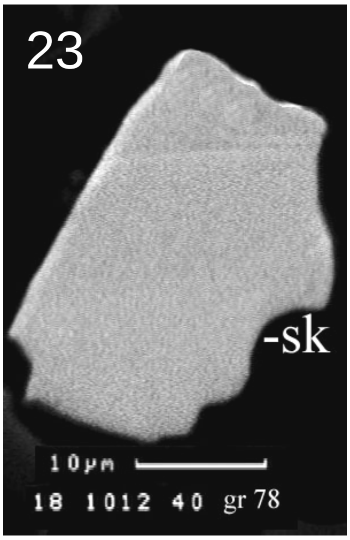
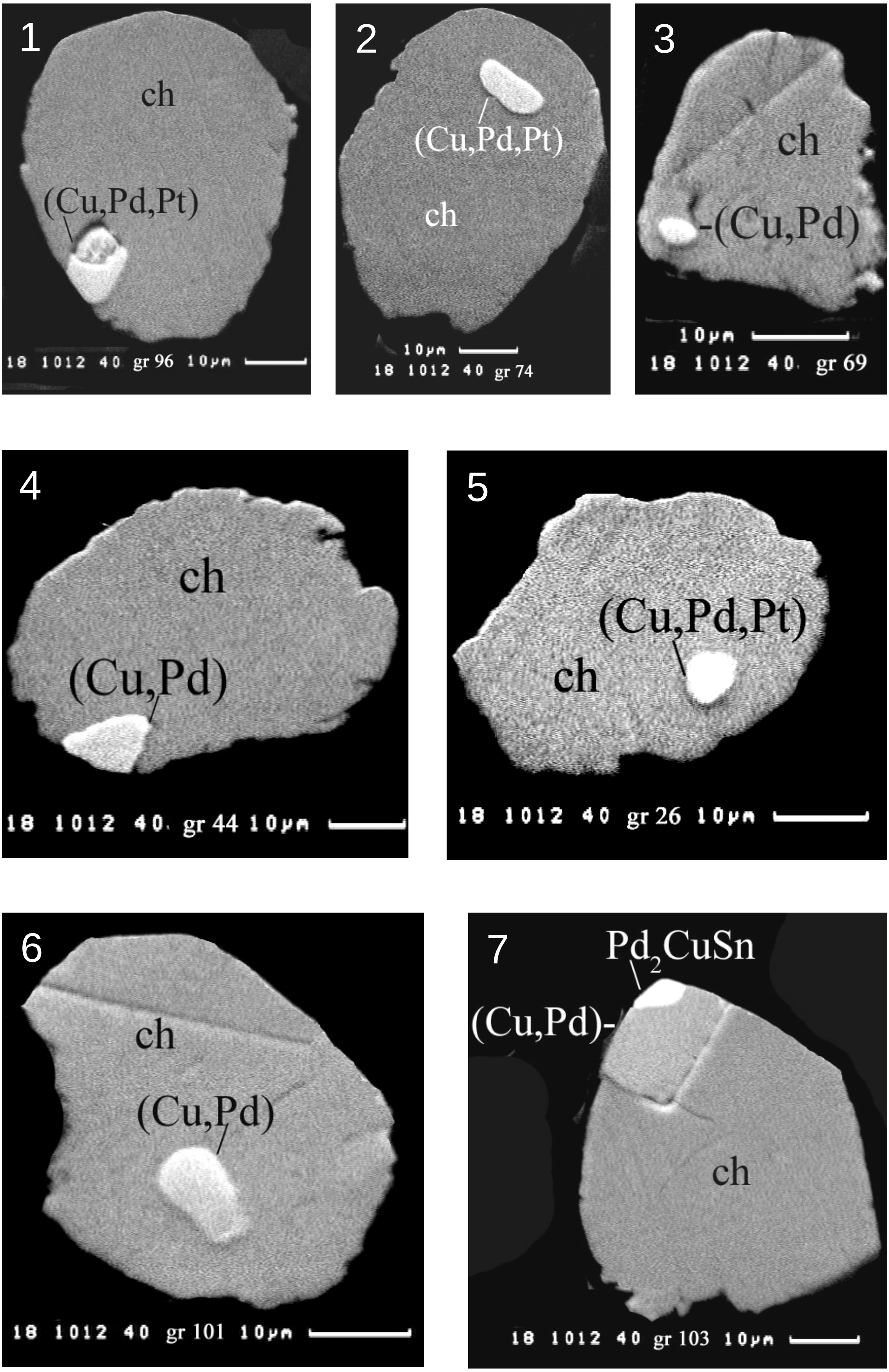
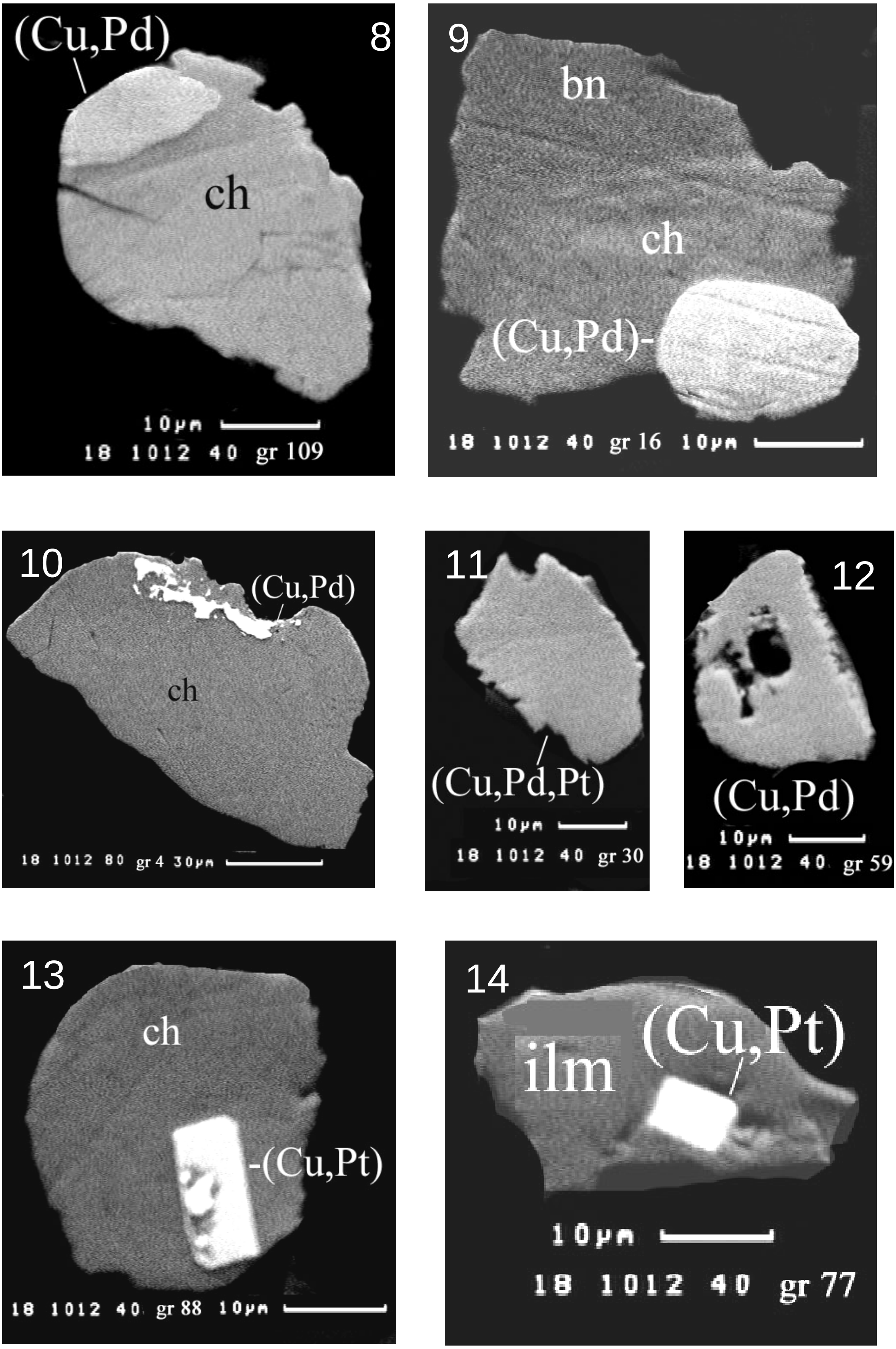

23
-sk
10μm
18 1012 40 gr 78

Plate 7

PGM grains containing (Cu,Pd,Pt) alloys (1-12), (Cu,Pt) alloys (13, 14) and nielsenite (15-17) in heavy mineral HS-concentrates of sample 90-18 1012, polished samples, SEM-image (BIE). Abbreviations: nls: nielsenite; sk: skaergaardite; at: atokite; Pd_2CuSn: cabriite; bn: bornite; ch: chalcosin and, ilm: ilmenite.


1
ch
(Cu,Pd,Pt)
18 1012 40 gr 96 10μm
2
(Cu,Pd,Pt)
ch
10μm
18 1012 40 gr 74
3
ch
-(Cu,Pd)
10μm
18 1012 40. gr 69
4
ch
(Cu,Pd)
18 1012 40. gr 44 10μm
5
(Cu,Pd,Pt)
ch
18 1012 40 gr 26 10μm
6
ch
(Cu,Pd)
18 1012 40 gr 101 10μm
7
Pd2CuSn
(Cu,Pd)-
ch
18 1012 40 gr 103 10μm



8
(Cu,Pd)
ch
10μm
18 1012 40 gr 109
9
bn
ch
(Cu,Pd)-
18 1012 40 gr 16 10μm
10
(Cu,Pd)
ch
18 1012 80 gr 4 30μm
11
(Cu,Pd,Pt)
10μm
18 1012 40 gr 30
12
(Cu,Pd)
10μm
18 1012 40 gr 59
13
ch
-(Cu,Pt)
18 1012 40 gr 88 10μm
14
ilm
(Cu,Pt)
10μm
18 1012 40 gr 77

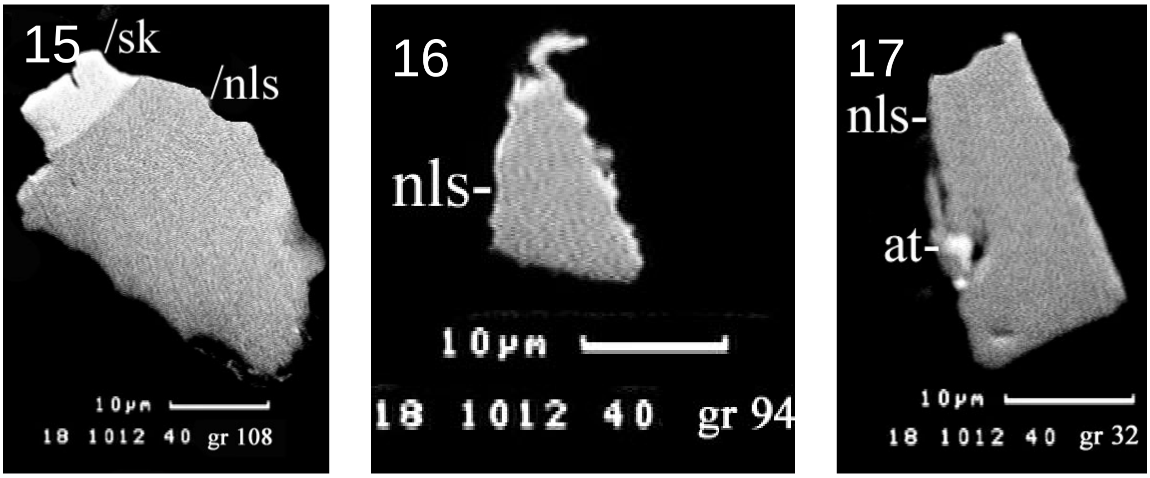
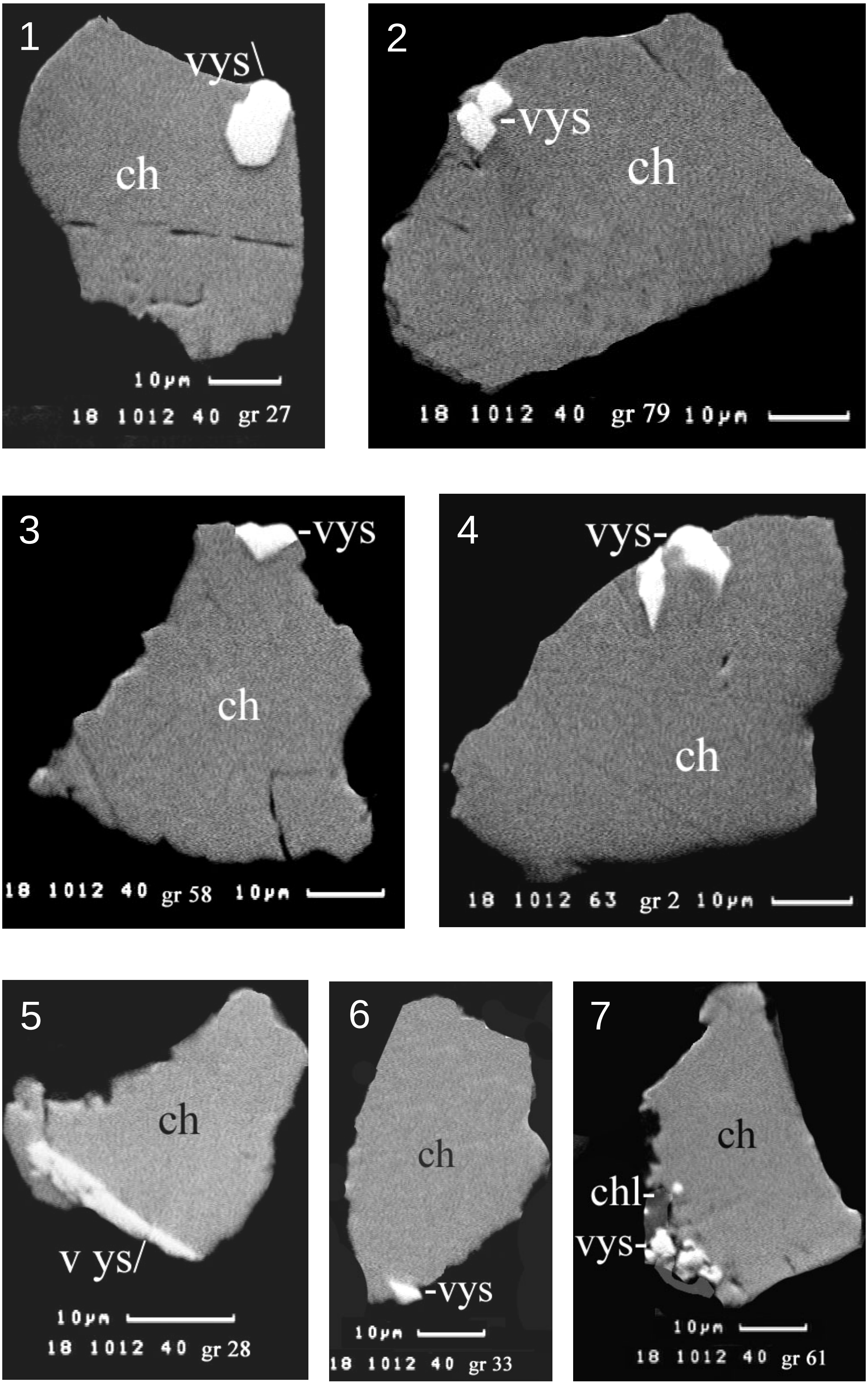
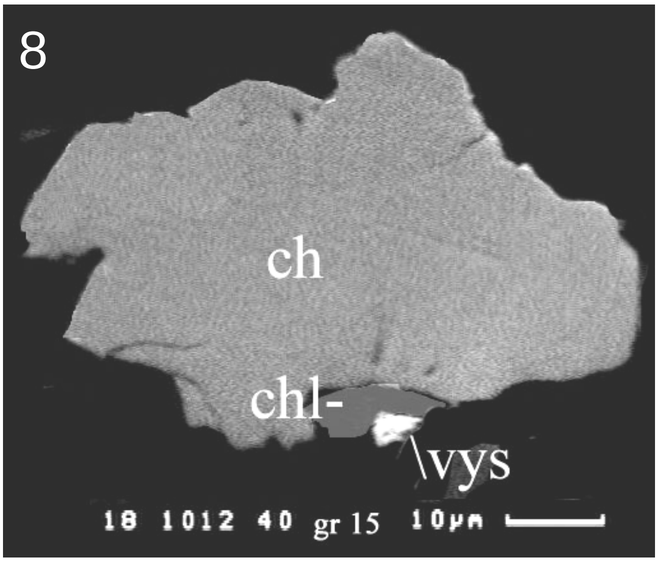
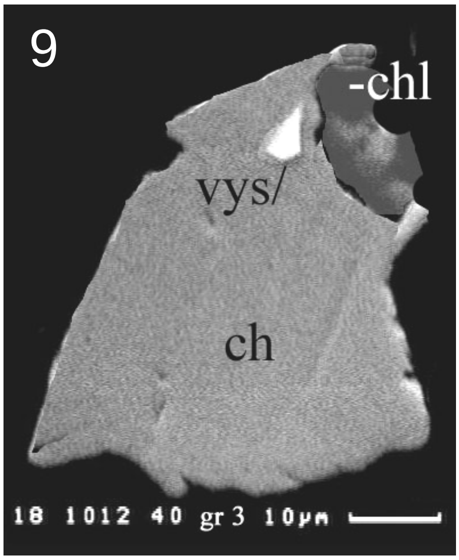

15
/sk
/nls
10μm
18 1012 40 gr 108
16
nls-
10μm
18 1012 40 gr 94
17
nls-
at-
10μm
18 1012 40 gr 32

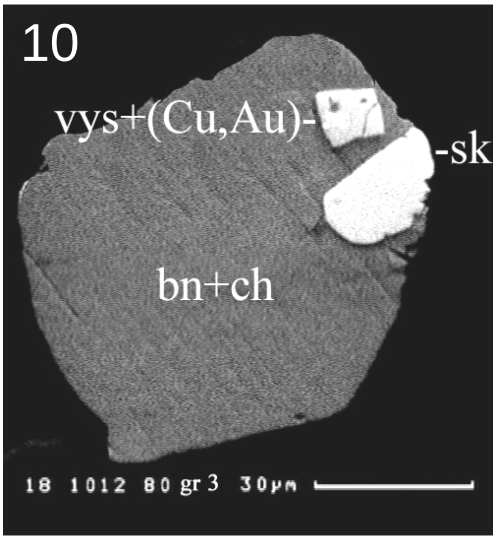
Plate 8

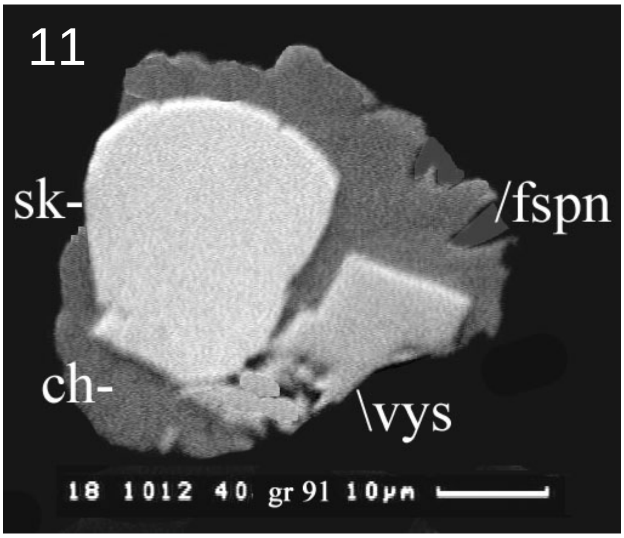
Globules and grains of sulphide with inclusions of vysotskite in the heavy mineral HS-concentrates of sample 90-18 1012; polished samples, SEM-image (BIE). Abbreviations: vys: vysotskite; sk: skaergaardite; bn: bornite; ch: chalcosine, ch: chlorite and fspn: ferrosaponite.

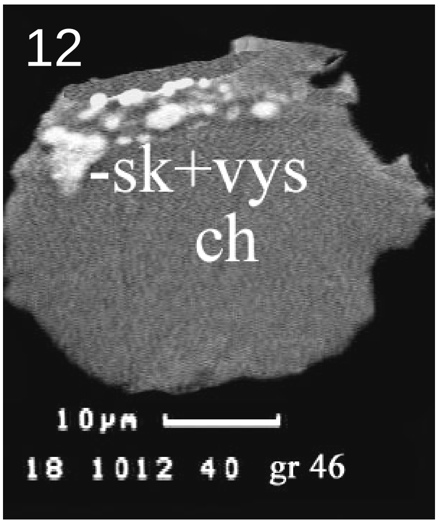

1
vys\
ch
10μm
18 1012 40 gr 27
2
-vys
ch
18 1012 40 gr 79 10μm
3
-vys
ch
18 1012 40 gr 58 10μm
4
vys-
ch
18 1012 63 gr 2 10μm
5
ch
v ys/
10μm
18 1012 40 gr 28
6
ch
-vys
10μm
18 1012 40 gr 33
7
ch
chl-
vys-
10μm
18 1012 40 gr 61

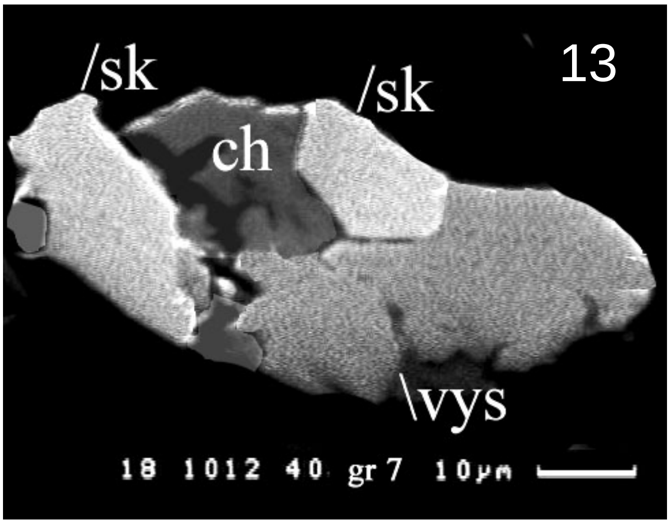

8
ch
chl-
\vys
18 1012 40 gr 15 10μm

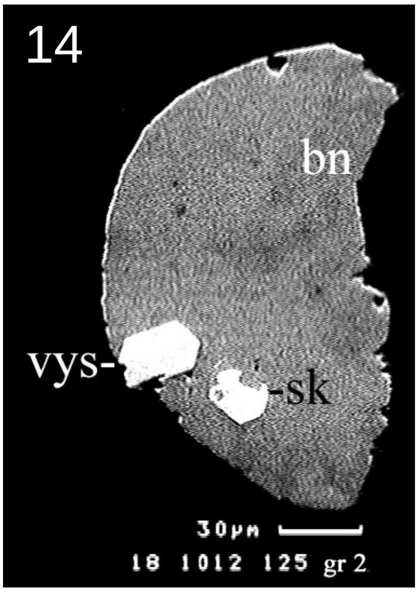

9
-chl
vys/
ch
18 1012 40 gr 3 10μm

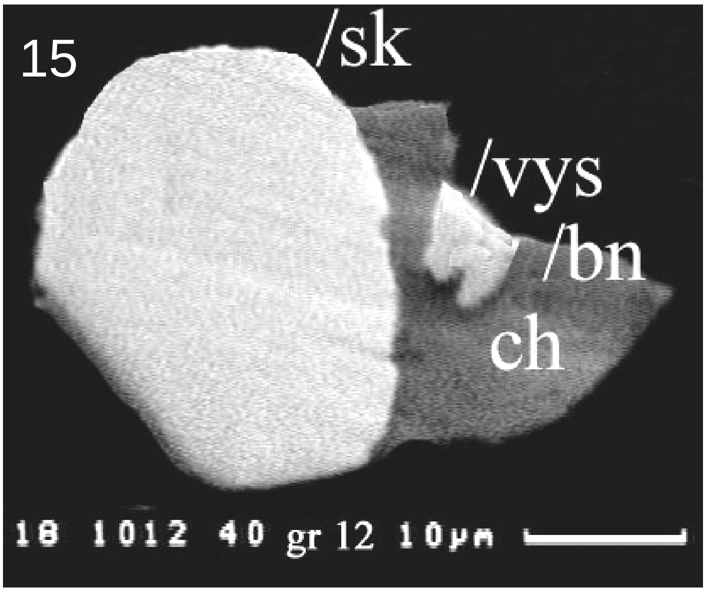

10
vys+(Cu,Au)-
-sk
bn+ch
18 1012 80 gr 3 30μm


11
sk-
/fspn
ch-
\vys
18 1012 40 gr 91 10μm


12
-sk+vys
ch
10μm
18 1012 40 gr 46


13
/sk
/sk
ch
\vys
18 1012 40 gr 7 10μm


14
bn
vys-
-sk
30μm
18 1012 125 gr 2


15
/sk
/vys
/bn
ch
18 1012 40 gr 12 10μm

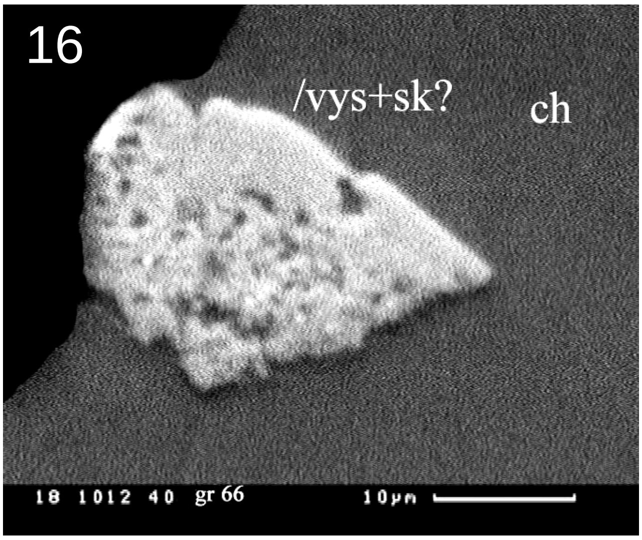
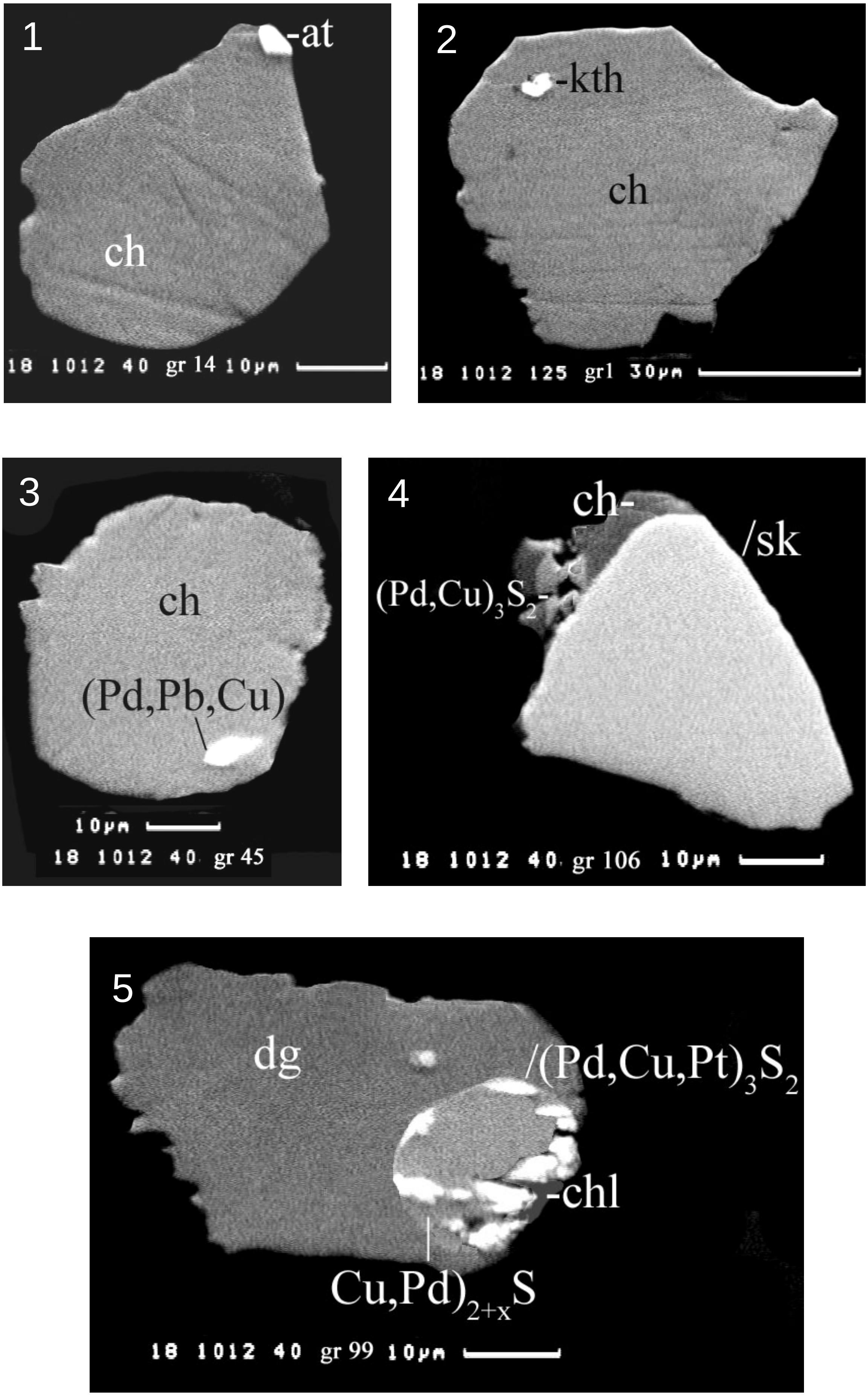
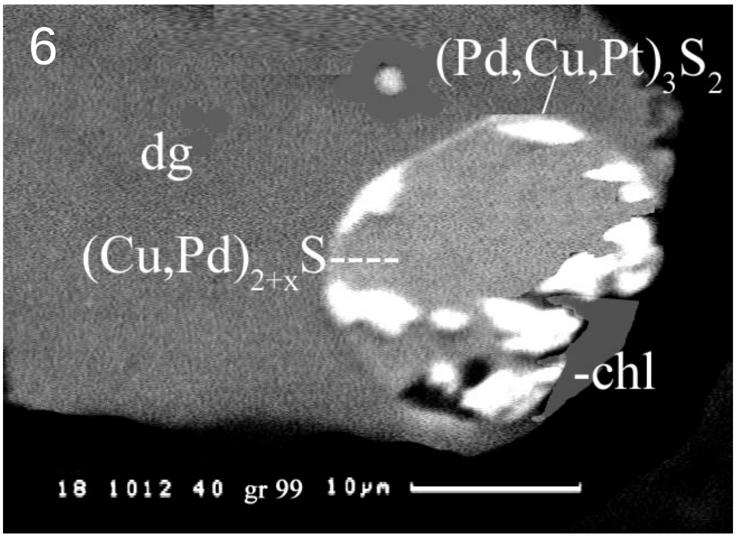

16
/vys+sk?
ch
18 1012 40 gr 66
10μm

Plate 9

Sulphide globules and grains with inclusions of: 1) atokite; 2) keithconnite (kth); 3) (Pd,Cu,Pb) alloy; and 4-6) unnamed $(Pd,Cu)_3S_2$) in the heavy mineral HS-concentrates of sample 90-18 1012; polished samples, SEM-image (BIE). Abbreviations; sk; skaergaardite, ch: chalcosine, dg; digenite, and chl: chlorite.


1
-at
ch
18 1012 40 gr 14 10μm
2
-kth
ch
18 1012 125 gr1 30μm
3
ch
(Pd,Pb,Cu)
10μm
18 1012 40 gr 45
4
ch-
/sk
(Pd,Cu)3S2-
18 1012 40 gr 106 10μm
5
dg
/(Pd,Cu,Pt)3S2
-chl
Cu,Pd)2+xS
18 1012 40 gr 99 10μm


6
(Pd,Cu,Pt)$_3$S$_2$
dg
(Cu,Pd)$_{2+x}$S----
-chl
18 1012 40 gr 99 10μm