DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2010/85

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

Part 10: Sample 90-18 988

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Abstract

The report presents the results of a mineralogical investigations of sample 90-18 988 from the Platinova Reef of the precious metal mineralization in the Skaergaard. The sample collect the whole rock between 988 and 989m in core 90-18. Assays give 987 ppb Pd, 150 ppb Au, and 105 ppb Pt for the 1m sample.

The sample (826 g) 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 (sieving -100 µm) after each crushing session. The residual coarse fraction >100 µm was re-crushed again until the entire sample has attained the desired maximum grain size.

After complete crushing, the material was passed with water through the following sieves: 1) <40, 2) 40-50, 3) 50-70, and 4) 70-100 µm. All fractions were processed through wet magnetic separation.

The non-magnetic parts of every fraction from the sample 90-18 988 were hydroseparated by means of the computer controlled device CNT HS-11 Monolayer polished sections were produced from all the the heavy HS-concentrates. The polished sections and one polished section of the whole rock were studied under the scanning electron microprobe. All magnetic fractions did not contain precious metal grains.

The gabbro in the sample 90-18 988 shows a characteristic reaction relationships between cumulus and inter-cumulus phase.: Rims of olivine and anorthite at the boundaries between accumulated grains of Fe-Ti-oxides and pyroxenes with exsolution texture. In general, this is a “dry” rock - H_2O-bearing minerals are locally represented in very insignificant amounts in an intergrowth with Cu-Fe-sulfides.

The HS-concentrates contain numerous sulfide grains identified as sulfide droplets. They are formed by one or more Cu-sulfides – bornite - (75 %), bornite+chalcosine (15 %), more rare bornite+chalcopyrite or chalcopyrite and chalcosine only. Several of these droplets and sulfide grains contain inclusions of various PGMs. Liberated (free) grains of precious metal mineral grains were also found.

Fine inclusions of CdS (<10 µm) are identified in of some sulfide globules. Occasionally, this mineral contains essential amounts (>1 wt.%) of Pd and Ag.

As the result of microprobe investigations HS concentrates, a representative selection of PGMs was studied in detail (33 particles, 41 precious metal mineral grains). The main precious metal minerals are the Pd sulfides: vysotskite PdS - 58.7 area % and vasilite $(Pd,Cu)_{16}S_7$ - 11.0 area %. Also, two (Au, Cu) alloys exist here in notable quantities: a phase with a composition close to $(Au,Pd,Pt)_3Cu$ (6.7 area %) and and a (Cu,Au,Zn,Ni) alloy (10.6 area %). Only one grain of (Cu,Pd) alloy is found in mineral concentrate. It is formed by: skaergaardite (5.7 area %), nielsenite (2.7 area %) and bornite. In addition the samples containes 6 other minerals (~5 % of all precious metal minerals of the sample).

The rare phases include: guanglinite $Pd_3(As,Te,Sn,Pb)$ – (1.3 area %), keithconnite $Pd_{3-x}Te$ (1.3 area %), zvyagintsevite $Pd_3(Pb,Sn)$ (0.4 area %), unnamed mineral with composition $(Pd,Ag,Cd,Cu,Tl)_4S$ (1.4 area %), unnamed $(Pd,Ag,Cu)_5S$ (0.2 area %) and Pd-Ag-bearing CdS.

The grain size of the precious metal minerals (ECD, 33 particles) varies from 4 to 45 μm, but fine grained particles dominate, and the average grain size is 12 μm.

The estimated bulk compositions of the sample (assays of whole rock in brackets) is (ppb): Pd 889 (987), Au 319 (150), Pt 34 (105). Most Pd is concentrated in Pd-sulfides (720 ppb), with minor Pd in Cu-Pd alloys (85 ppb) and other PGMs (84 ppb). Pt-native minerals were not found. Pt was identified in vysotskite (~65 % of all Pt), Au-Cu alloys and Pd-Cu alloys. Au is found in (Au,Cu) alloys (~98% of all Au); with minor Au in Au skaergaardite.

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

Introduction

The report describes the mineralogy of sample 90-18 988 from the Pd3 level in the "Platinova Reef" of the Skaergaard intrusion (Nielsen et al., 2005) .The mineralogical report has been prepared by N.S. and V.N. Rudashevsky on the request of the geological Survey of Denmark and Greenland.

The mineralogical report is based on the data recovered from HS concentrates produced using new patented model of Hydroseparator CNT HS-11 and one polished section of the whole rock. Monolayer polished sections of HS concentrates and one polished section of gabbro were studied using electron microscopy and electron microprobe analysis (Camscan-4DV, Link AN-10 000). The report gives descriptions of the grain characteristics, the parageneses, and the compositional variations within the identified groups of minerals, alloys, sulfide droplets and host gabbro.

Sample 90-18 988

Sample 90-18 988 was collected from BQ drill core #90-18, and covers the interval between 988 and 989 m in the Pd3 level of the Platinova Reef. Assays give 987 ppb Pd, 150 ppb Au, and 105 ppb Pt for this interval (Watts, Griffis & McOuat, 1991). The core has previously been sampled for other purposes. The sample collects 1/3 of the diameter of preserved core.

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003) "PGE and sulfide phases of the precious metal mineralization of the Skaergaard intrusion, Part 1: sample 90-23A 807". One polished section was prepared from fragment of the sample (Plate 1). The heavy mineral concentrates, enriched by precious metal minerals and sulfides (Plate 2) were obtained using a new, patented, model of the computer controlled Hydroseparator CNT HS-11, and newly patented glass separation tube (GST) (Rudashevsky, Rudashevsky, 2006, 2007) – see www.cnt-mc.com.

The core material was crushed to <100 µm. After complete grinding, the sample was passed through standard sieves with water (wet sieving): <40 µm (468.5 g) , 40-50 µm (70.2 g), 50-70 µm (100.9 g), 70-100 µm (141.8 g), Total 781.4 g (loss 44.3 g).

After wet magnetic separation, the powdered fractions <40 µm, 40-50 µm, 50-70 µm, 70-100 µm were passed through hydroseparator CNT HS-11. Monolayer polished sections were produced from all heavy mineral HS concentrates.

Results

Rock forming minerals and sulfide mineralogy

Silicates and oxides

The silicates and oxides related to sulfides are: 1) *monoclinic ferrous pyroxene*, Mg# = 0.63-0.64 (Table 1, analyses 1-3); 2) *orthorhombic ferrous pyroxene*, Mg# = 0.56-0.57 (Table 1, analyses 4-6); 3) *plagioclase I*, An_{45-51} (Table 1, analyses 7-9) and *plagioclase II*, An_{88} (Table 1, analysis 10); 4) *Fe-rich olivine*, Mg# = 0.45 (Table 1, analyses 11, 12); Fe-Ti oxides including 5) *ilmenite* (Table 1, analyses 13-15) and 6) *titaniferous magnetite* (Table 1, analyses 16, 17). Monoclinic and orthorhombic pyroxenes form typical exsolution textures.

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 in sample 90-18 988 shows a characteristic reaction relationships of cumulus and intercumulus phaseswith rims of Fe-rich olivine and plagioclase between accumulated grains of Fe-Ti-oxides and pyroxene (plate 1)

Sulfides

The bulk rock is relatively poor in sulfides. Just several rare grains of bornite in ilmenite and in pyroxenes were identified (Plate 1, #*4*).

The non-magnetic heavy mineral concentrates are ilmenite-rich products (>97 %) enriched in grains of sulfides and PGMs (see Plate 2). The sulfide grains are represented by droplet-like microglobules: bornite (Plate 3, #*1-10 etc*), and bornite-chalcosine (Plate 3, #*24-26, 28* etc), or irregular grains composed of bornite (Plate 3, #*11-22* etc), bornite-chalcosine (Plate 3, #*23, 27* etc), chalcosine (Plate 3, #*29*), bornite-chalcopyrite (Plate 3, #*30*) or chalcopyrite (Plate 3, #*31*) up to 0.1 mm in size.

Two rock-forming minerals are seen to have contacts with sulfide and PGM grains - ilmenite (Plate 3, #*13, 14*), and chlorite (Plate 3, *15*). We should also note the occurrence of fine (<5 μm) inclusions of CdS in the marginal parts of several sulfide grains (Plate 3, #11).

The majority (~75 %) of the sulfide grains are composed of bornite, fewer of bornite+chalcosine (15 %), and rare are grains of bornite+chalcopyrite, chalcosine, or chalcopyrite. Bornite and chalcosine, as well as bornite and chalcopyrite form exsolution textures in sulfide micro-globules and grains (see Plate 3, #*23-28, 30*).

The chemical compositions of bornite (Table 2, analyses 1-19, the average analysis 20), chalcosine (Table 2, analyses 21, 22) and chalcopyrite (Table 2, analysis 23) are all close to stoikiometry.

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

Recovery

No PGM grain found during SEM studies of the polished section of gabbro #90-18 988.

The heavy mineral HS concentrates have yielded many precious metal grains. Their representative selection of 33 fine particles in <40 μm and 50-70 μm fractions of the heavy mineral HS concentrates was studied in detail. In total, 11 different PGE and Au minerals are documented in the sample 90-18 988. They include (Table 3):

1. *vysotskite* (Pd,Pt)S – 17 grains,
2. *vasilite* $(Pd,Cu)_{16}S_7$ –6 grains
3. *unnamed* $(Au,Pd,Pt)_3Cu$– 5 grain,
4. *alloy*(Cu,Au,Ni,Zn) – one grains,
5. *skaergaardite* (Pd,Au,Pt)(Cu,Zn,Fe)– one grain,
6. *nielsenite* $Pd(Cu,Fe)_3$ – one grain,
7. *keithconnite* $Pd_{3-x}Te$ – 2 grains,
8. *guanglinite* $Pd_3(As,Te,Sn,Pb)$ – 4 grains,
9. *zvyagintsevite* $Pd_3(Pb,Sn)$ – 2 grains,
10. *unnamed* $(Pd,Ag,Cd,Cu,Tl)_4S$ – one grain,
11. *unnamed* $(Pd,Ag,Cu)_5S$ – one grain.

Besides, Pd- and Ag-bearing CdS grains were found together with unnamed $(Pd,Ag,Cu)_5S$ as inclusions in bornite. The volumetric proportions are calculated from the area of grains of these minerals (Table 3 and Fig. 1).

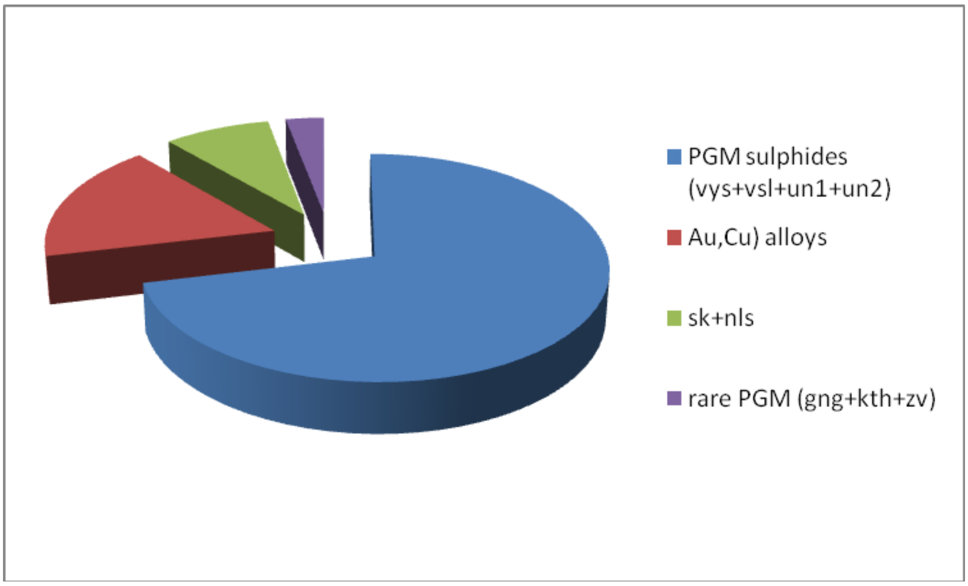

Fig. 1. Precious metal minerals (area %) from the heavy mineral HS concentrates of the sample 90-18 988; vys – vysotskite, vsl – vasilite, sk-skaergaardite, nls – nielsenite, gng – guanglinite, kth – keithconnite, zv – zvyagintsevite, un_1 – $(Pd,Ag,Cd,Cu,Tl)_4S$, un_2 – unnamed $(Pd,Ag)_5S$.

Grain size

Grain sizes were measured as effective diameters of the grains (ECD) using imageJ software. The grain size varies (n=33 particles) from 4 to 45 µm with the average of 12 µm (Table 4; Fig. 2). Sizes of precious metal mineral grains are distributed as follows:

Grain size, µm	Number of grains
0-10	15
10-20	13
20-30	4
30-40	0
40-50	1
Total	33

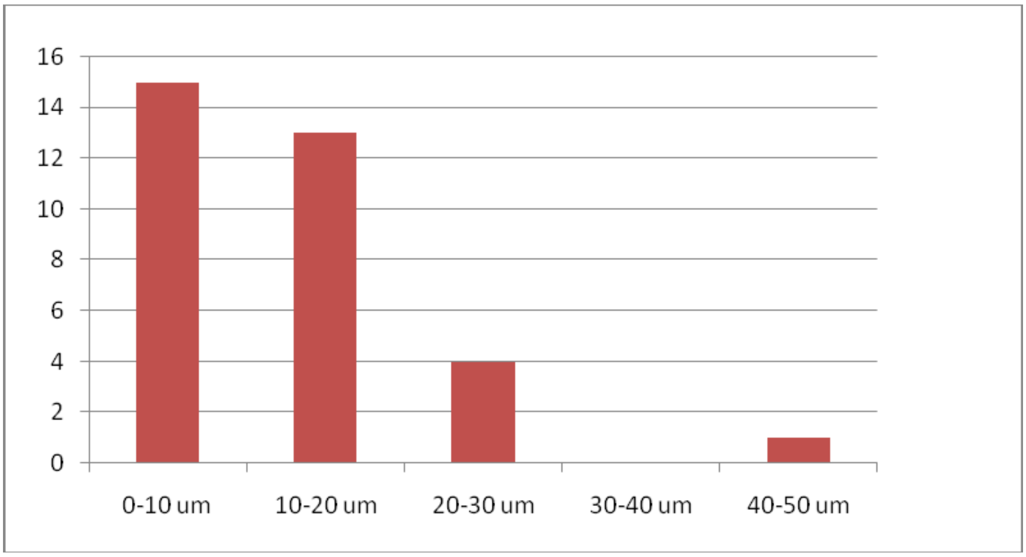

Figure 2. The distribution of grain sizes of precious metal mineral grains from the heavy mineral HS concentrates of the sample 90-18 988 (n=33, ECD_{avg} = 12.3 μm).

The histogram of grain sizes (Fig. 2) shows a lognormal distribution for given population.

The SEIs (scanning electron images) show that majority of precious metal mineral grains are well preserved and have kept their primary shapes and sizes (Plates 4-7). Grains have not been broken during production of the concentrates. Most PGM grains occuir as inclusions in Cu-Fe sulfide globules and grains.

Liberation

Perfect separation of accessory minerals have been achieved by gentle crushing/disintegration of the studied sample. The method of disintegration allows to preserve primary grain size and to recover petrographic and mineralogical information on the development of a model for the genesis of the ineralisation The concentrates provide full information for the reconstruction of the primary shapes and sizes of accessory minerals, paragenesises, and the relationships with the precious minerals paragenesis and the host rock.

In the heavy mineral HS concentrates of the sample 90-18,988 (n=33 grains) the precious metal mineral grains occur in the following mineral associations (Fig. 3; Table 5):

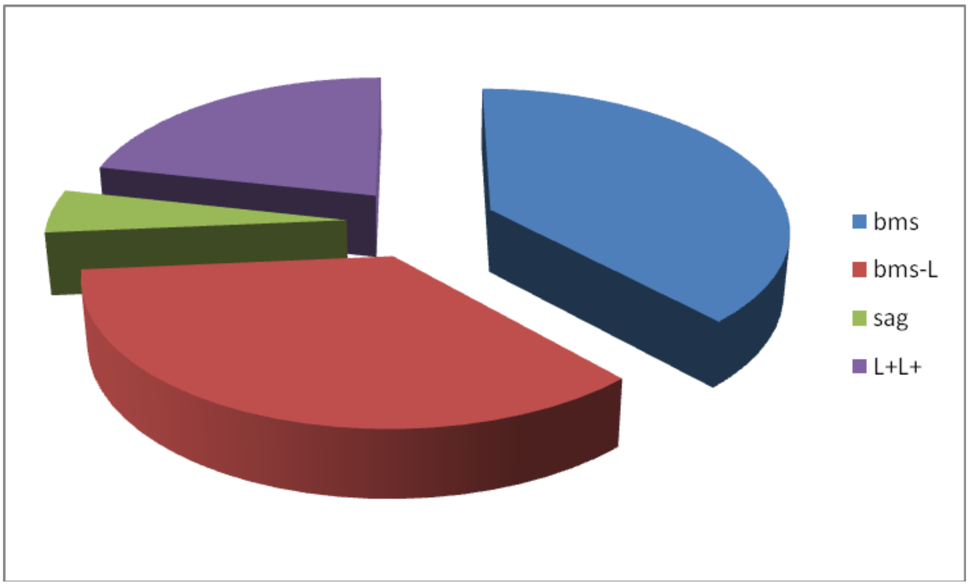

Figure. 3. Liberation distribution of PGE- and gold minerals in the heavy mineral HS concentrates of the sample 90-18 988; **bms** - precious metal minerals, attached to base metal sulfides; **bms-L** - precious metal minerals exposed >90%, attached to bms; **sag** – PGM attached to base metal sulfides and gangue; **L** – liberated (free) precious metal minerals; **L^{+}** - two or more liberated (free) precious metal minerals.

Description and chemistry of precious metal minerals

Vysotskite (Pd,Cu,Pt,Ni)S

Description

Vysotskite (58.7 area % of all precious metal minerals) is found in the heavy mineral HS concentrates as inclusion in bornite globules (Plate 4, #*1, 2*) and in bornite grains of irregular shape (Plate 4, #*3-15*), or as intergrowth with small bornite grain (Plate 6, #*16*). As a rule, vysotskite grains are found in the marginal part of bornite matrix (Plate 4, #*1-5, 8-15*). Small vysotskite grains (<10 μm) can also be found as inclusions in the central part of bornite hosts (Plate 4, #*5-7*). Sometimes, small inclusions of CdS occur in bornite together with vysotskite (Plate 4, #*6*). Vysotskite occur as irregular-shape grains (see Plate 4).

Grain sizes of vysotskite (17 grains) are from 4 to 45 μm with an average of 13 μm (Table 3).

Mineral chemistry

The average chemical composition of vysotskite is obtained from 11 analyses from 10 different grains (Table 6, analyses 1-11). Vysotskite grains may be zoned in Pt (Plate 4, #9; Table 6, analyses 6, 7). The average composition of vysotskite (Table 6, analysis 12) is (wt. %): Pd 70.3, Pt 2.7 Cu 1.8, Fe 0.5, Ni 0.7, S 23.3, Total 99.6. The composition corresponds to the formula:

$$(Pd_{0.91}Cu_{0.04}Pt_{0.02}Ni_{0.02}Fe_{0.01})_{1.00}S_{1.00}.$$

Typical admixtures in vysotskite are the following: Pt up to 22.5 %, Cu 0.3-8.6 %, Ni up to 5.0 %, Fe up to 1.2 %.

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

Description

Vasilite (11.0 area % of precious metal minerals) is found in the heavy mineral HS concentrates as inclusion in sulfide globules (bornite, chalcosine) (Plate 5, #1, 2) and irregular shape aggregates (Plate 5, #3; Plate 6, #1), or as liberated vasilite (Plate 6, #3) and vasilite-keithconnite-(Au,Cu) alloy grains (Plate 6, #3). Vasilite occur as irregular shape grains (see Plate 5; Plate 6, #1, 3).

Grain size of vasilite (6 grains) varies from 4 to 20 µm with an average of 10 µm (see Table 3).

Mineral chemistry

The chemical composition of vasilite is constrained by 6 analyses from 6 individual grains (Table 7, analyses 1-6). The average composition of vasilite (Table 7, analysis 7) is (wt. %): Pd 72.6, Cu 13.3, Fe 0.9 S 12.7, Total 99.5. The composition corresponds to the formula:

$$(Pd_{12.01}Cu_{3.70}Fe_{0.28})_{15.99}S_{.7.00}\ .$$

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

The mineral skaergaardite, PdCu, was named and described by the authors and others of this report from samples from the Skaergaard mineralization (Rudashevsky e.a., 2004).

Only one skaergaardite grain with an irregular shape and a size of 20.5 µm (5.7 area % of all PGE and gold minerals – see Table 3)was found in the heavy mineral HS concentrates (Plate 7, #1; Table 8, analysis 1).. It forms an intergrowth with nielsenite ($Pd(Cu,FE)_3$) and

Cu-Fe sulfides (bornite and chalcosine). Characteristic admixtures in skaergaardite are: Pt 2.1 %, Au 5.1 %, Fe 2.5 %, Zn 3.4 %.

Nielsenite Pd(Cu,Fe)$_3$

The mineral nielsenite $PdCu_3$ was named and described by some of the authors of this report and others from samples from the Skaergaard mineralization (McDonald e. a., 2008).

Only one grain of nielsenite with an irregular shape and a size of 14 μm (2.7 area % of all PGE and gold minerals – see Table 3)) was found in the heavy mineral HS concentrates (Plate 7, #*1*; Table 8, analysis 2). It forms an intergrowth with skaergaardite and Cu-Fe sulfides (bornite and chalcosine

Un-named (Au,Pd,Pt)$_3$(Cu,Fe)

The un-named alloy with the composition $(Au,Pd)_3Cu$ (6.7 area % of all precious metal minerals) is found as inclusions in bornite host (Plate 6, #*1, 2*), or as liberated precious metal mineral grains (Plate 6, #*3-5*) in the heavy mineral HS concentrates. These liberated grains occur as single grains (Plate *6, #4, 5*), or as intergrowth of (Au,Cu) alloy with vasilite and keithconnite (Plate 6, #*3*). Au_3Cu alloy occurs in the form of irregular grains ranging in size between 3 and 15 μm with an average of 9 μm (see Table 3).

The chemical composition of this un-named (Au,Cu) alloy is given in 4 analyses from 4 individual grains (Table 9, analyses 1-4). The average composition of $(Au,Pd)_3Cu$ (Table 9, analysis 5) is (wt. %): Pd 17.9, Pt 4.7 Au 64.4, Cu 10.7, Fe 1.5, Total 99.7. The composition of this phase corresponds to the formula

$$(Au_{1.83}Pd_{0.94}Pt_{0.14}Ag_{0.02})_{2.93}(Cu_{0.93}Fe_{0.15})_{1.08}.$$

Alloy (Cu,Au,Ni,Zn)

Also found is one liberated (free) grain of (Cu,Au,Ni,Zn) alloy, with an irregular shape, and a size of 28 μm (10.6 area % of all precious metal minerals) (see Plate 6, #*6*; Table 9, analysis 6).

Guanglinite (Pd,Cu)$_3$(As,Te,Sn,Pb)

Four very small grains of guanglinite (2-7 μm, the average - 4.5 μm; 1.3 area % of all precious metal minerals) were found as inclusions in Cu-Fe sulfides (bornite and chalcosine) –

Plate 6, #*2*; Plate 7. #*2, 3*; Table 10, analyses 1-3, the average analysis 4. The guanglinite grains are often associated with zvyagintsevite and (Au,Cu) alloy (Plate 6, #*2*).

Keithconnite $Pd_{3-x}Te$

Two grains of keithconnite (Table 10, analysis 6) owith irregular shapes, and ranging between 6 and 7 μm (1.3 area % of all PGE and gold minerals – see Table 3) were found as an inclusions in a bornite host (Plate 7, #*4*) and in an intergrowth with vasilite and (Au,Cu) alloy (Plate 6, #*3*).

Zvyagintsevite $Pd_3(Pb,Sn)$

Zvyagintsevite (0.4 area % of all precious metal minerals; Table 10, analysis 5) occurs as inclusions in bornite host (Plate 6, #*2*; Plate 7, #5). Zviagintsevite occurs as intergrowth with guanglinite, (Au,Cu) alloy, or with unnamed $(Pd,Ag,Cd,Cu,Tl)_4S$. The grains usually have irregular shapes and range in size between 3 and 5 μm.

Un-named $(Pd,Ag,Cd,Cu,Tl)_4S$

One PGM grain of the unusual composition - $(Pd,Ag,Cd,Cu,Tl)_4S$ (Table 11, analysis #1) was found in an intergrowth with zvyagintsevite in a bornite host (see Plate7, #5). about the size of the grain is app. 10 μm (1.4 area % of all precious metal minerals).

Un-named $(Pd,Ag,Cu)_5S$

One grain of an un-named PGM with the composition $(Pd,Ag,Cu)_5S$ (Table 11, analysis 2) was found as tiny inclusions (~4 μm, 0.2 area % of all precious metal minerals) in a bornite host (see Plate 7, #*6*)., Other tiny inclusions of Pd- and Ag-bearing CdS occur together with this un-named PGM in the bornite host (Table 11, analysis #3).

Bulk composition of PGMs of the sample 90-18 988

The relative concentrations of Pd, Au and Pt in the sample 90-18 988 can be calculated from the total concentrations of precious metals (assay), the recovery, the modal proportions, the chemical compositions (Tables 3 and 6-11), and the ideal densities of precious metal minerals. The estimated bulk composition of the sample (assays of whole rock in brackets) is (ppb): Pd 889 (987), Au 319 (150), Pt 34 (105). Pd is concentrated in Pd-sulfides (720 ppb, ~80 %) with a minor fraction in (Cu,Pd)alloys (skaergaardite, nielsenite,

~10 %) and other PGMs (~10 %). No Pt minerals were found. Pt is hosted in vysotskite (~65 % of all Pt), Au-Cu alloys, and Pd-Cu alloys. Au is hosted in (Au,Cu) alloys (~98% of all Au), withremaining Au in skaergaardite.

Discussion

PGM-paragenesis

The data shows that the main PGMs in the studied sample are Pd sulfides (vysotskite, vasilite and rare un-named Pd-PGMs: 66.4 area %). (Au,Cu) alloys (17.3 area %) and other PGMs (16.3 area %) compose the remaining proportion of the precious metal mineral paragenesis – see Figure 1.

All the observations and the inter-grain relations (Plates 4-7) suggest that all PGEs are part of a single paragenesis together with Cu-Fe sulfides. The Cu-Fe sulfides and precious metal minerals are synchronous and crystallized later than rock-forming minerals: plagioclase, clinopyroxene, orthopyroxene, ilmenite and titaniferous magnetite.

Several geochemical peculiarities of the sample 90-18 988 are related to unusual occurrence of rare heavy metals in both sulfide phases and precious metal phases. The perculiarities are: occurrence of Cd-minerals in sulfide globules, including CdS (sometimes Pd- and Ag-bearing) and un-named PGM $(Pd,Ag,Cd,Cu,Tl)_4S$; and the unusual composition of Ni-Zn-bearing (Cu,Au) alloy that obviously is not accidental as witnessed by the Zn-rich skaergaardite composition (Zn>Fe).

These geochemical peculiarities can be caused by replacement of “primary” skaergaardite by Pd sulfidesmineralization. The process liberates Zn and its crystallochemical analogue – Cd,. The reactions lead to Zn-rich skaergaardite and Zn-bearing (Cu,Au) alloys, as well as Cd-minerals, including Cd-bearing PGMs.

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Tables

Table 1 **Chemical compositions (wt.%) and formulas of rock forming minerals in gabbro sample 90-18 988**

Mineral	cpx	cpx	cpx	opx	opx	opx	plag	plag	plag	plag	ol	ol	ilm	ilm	ilm	ti-mt	ti-mt
analysis																	
SiO_2	50.11	50.32	50.11	50.32	50.96	50.11	55.89	55.25	55.03	45.87	34.12	34.03	nd	nd	nd	nd	nd
TiO_2	0.67	0.67	0.67	nd	0.33	0.31	nd	0.33	nd	nd	nd	nd	51.09	50.75	50.58	16.36	13.78
Al_2O_3	1.70	1.89	1.89	1.13	0.95	0.97	27.60	27.22	27.98	34.55	nd	nd	nd	nd	0.95	4.12	5.32
Fe_2O_3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.39	4.75	4.34	31.88	35.43
FeO	13.60	11.93	14.28	22.53	24.43	26.19	0.26	0.77	0.26	nd	44.89	44.44	42.88	41.40	41.38	44.69	42.68
MnO	0.39	0.26	0.26	0.65	0.78	0.65	nd	nd	nd	nd	0.51	0.67	0.65	0.65	0.52	0.38	nd
MgO	13.60	12.44	12.77	18.91	19.07	19.73	nd	nd	nd	nd	20.32	20.18	1.33	1.99	1.99	1.31	1.45
CaO	19.72	20.56	19.58	2.52	1.54	1.68	10.07	9.79	9.51	18.03	nd	nd	nd	nd	nd	nd	nd
Na_2O	nd	nd	nd	nd	nd	nd	5.39	5.93	6.33	1.32	nd	nd	nd	nd	nd	nd	nd
K_2O	nd	nd	nd	nd	nd	nd	0.48	0.36	0.36	nd	nd	nd	nd	nd	nd	nd	nd
V_2O_3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.59	nd	nd	1.60	1.71
Total	99.79	99.25	99.57	99.64	100	99.64	99.69	99.66	99.47	99.77	99.84	99.32	98.91	99.53	99.76	100.34	100.38
Cations																	
Si	1.91	1.93	1.92	1.94	1.95	1.93	2.53	2.50	2.47	2.12	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Ti	0.02	0.02	0.02	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.97	0.96	0.95	3.60	3.01
Al	0.08	0.09	0.09	0.05	0.04	0.04	1.47	1.45	1.48	1.88	0.00	0.00	0.00	0.00	0.03	1.42	1.82
Fe^{3+}	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.05	0.09	0.08	7.01	7.75
Fe^{2+}	0.43	0.42	0.46	0.84	0.84	0.84	0.01	0.03	0.01	0.00	1.10	1.09	0.91	0.87	0.86	10.93	10.38
Mn	0.01	0.01	0.01	0.02	0.03	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.09	0.00
Mg	0.77	0.71	0.73	1.08	1.09	1.13	0.00	0.00	0.00	0.00	0.91	0.89	0.05	0.07	0.07	0.57	0.63
Ca	0.81	0.84	0.80	0.10	0.06	0.07	0.49	0.47	0.46	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.52	0.55	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.38	0.40
O basis	6 O	6 O	6 O	6 O	6 O	6 O	8 O	8 O	8 O	8 O	4 O	4 O	2 cat.	2 cat.	2 cat.	24 cat.	24 cat.

Abbreviations: cpx: clinopyroxene, opx:orthopyroxene, plag: plagioclase, ol: olivine, ilm: ilmenite, ti-mt: titanomagnetite. Cat.: cations.
Nd: no data/not determined

Table 2: Chemical compositions (wt.%) and formulas of Cu-Fe sulphides from the heavy mineral HS concentrates of the sample 90-18 988

			analysis				*cations*			
Analysis	**Grain#**	**Association**	**Cu**	**Fe**	**S**	**Total**	***Cu***	***Fe***	***S***	***Total***
Bornite										
1	40-2	vsl+bn	62.5	11.4	25.8	99.7	*4.94*	*1.03*	*4.03*	*10*
2	40-2b	bn	62.1	11.6	25.5	99.2	*4.93*	*1.05*	*4.02*	*10*
3	40-2c	bn	62.6	11.1	25.4	99.1	*4.99*	*1*	*4.01*	*10*
4	40-2g	bn	63	11.1	25.3	99.4	*5.01*	*1*	*3.99*	*10*
5	40-2i	bn	62.7	11.2	25.5	99.4	*4.98*	*1.01*	*4.01*	*10*
6	40-4	UN1+zv+bn	63.3	11.1	25.5	99.9	*5.01*	*1*	*4*	*10*
7	40-5a	bn	63.1	11.6	26	100.7	*4.94*	*1.03*	*4.03*	*10*
8	40-6	vys+CdS+bn	63.5	10.5	25.3	99.3	*5.06*	*0.95*	*3.99*	*10*
9	40-10	vsl+Au_3Cu+bn	63.5	11	25.7	100.1	*5*	*0.98*	*4.01*	*10*
10	40-12a	bn	62.8	11.1	25.3	99.2	*5.01*	*1*	*3.99*	*10*
11	40-17a	bn	63.8	11.1	25.8	100.7	*5*	*0.99*	*4.01*	*10*
12	40-19	vys-bn	62.9	10.9	25.3	99.1	*5.01*	*0.99*	*4*	*10*
13	40-21	vys-bn-chl	63	11	25.4	99.4	*5.01*	*0.99*	*4*	*10*
14	40-23	vsl-bn	62.6	11.1	25.6	99.3	*4.97*	*1*	*4.03*	*10*
15	40-23a	bn-chc	63.1	10.8	25.3	99.2	*5.03*	*0.97*	*4*	*10*
16	40-24	vsl+kth+Au_3Cu+bn	62.9	11.3	25.3	99.5	*5*	*1.02*	*3.98*	*10*
17	100-1a	bn-chc	63.2	10.8	25.4	99.4	*5.02*	*0.97*	*4*	*10*
18	100-1c	bn	62.7	11.3	25.5	99.5	*4.98*	*1.02*	*4*	*10*
19	100-2	vsl-bn	63.6	11.1	25.4	100.1	*5.02*	*1*	*3.98*	*10*
20		average	63	11.1	25.5	99.6	*5*	*1*	*4*	*10*
Chalcosine										
21	40-2k	chc	70.8	0.9	20.8	99.7	*1.95*	*0.03*	*1.03*	3
22	100-1a	bn-chc	78.3	0.7	20.4	99.4	*1.97*	*0.02*	*1.01*	3
Chalcopyrite										
23	40-4d	cp	34.5	30.2	34.7	99.4	*1*	*1*	*2*	*4*

Abbreviations: vsl: vasilite; bn: bornite; UN1: unknown 1; zv: zvyagintsevite; vys: vysotskite; chl: chlorite; chc: chalcocine; kth: keithconnite; cp: chalcopyrite.

Table 3 Platinum group minerals and gold minerals of the heavy mineral HS concentrates, sample 90-18 988

#	Mineral	General formula	n	Area µm2	#%	Area %	ECD_{min}	ECD_{avg}	ECD_{max}
1	Visotskite	(Pd,Cu,Ni)S	17	3422	41.5	58.7	3.6	12.9	44.8
2	Vasilite	$(Pd,Cu)_{16}S_7$	6	641	14.6	11	3.6	9.8	19.9
3	Au_3Cu	$(Au,Pd,Pt)_3(Cu,Fe)$	5	390	12.2	6.7	3.2	8.6	15.1
4	(Cu,Au) alloy	(Cu,Au,Ni,Zn)	1	620	2.4	10.6		28.1	
5	Skaergaardite	(Pd,Au,Pt)(Cu,Zn,Fe)	1	330	2.4	5.7		20.5	
6	Nielsenite	$Pd(Cu,Fe)_3$	1	160	2.4	2.7		14.3	
7	Keithconnite	$Pd_{3-x}Te$	2	76	4.9	1.3	6.6	6.9	7.3
8	Guanglinite	$Pd_3(As,Te,Sn,Pb)$	4	74	9.8	1.3	2.5	4.5	7.2
9	Zvyagintsevite	$Pd_3(Pb,Sn)$	2	24	4.9	0.4	2.5	3.7	4.9
10	unknown $_1$	$(Pd,Ag,Cd,Cu,Tl)_4S$	1	80	2.4	1.4		10.1	
11	unknown $_2$	$(Pd,Ag,Cu)_6S$	1	13	2.4	0.2		4.1	
	Total		41	5830	100	100			

Comment: Grain sizes in microns (µm)

Table 4 Sizes of precious metal mineral grains from the heavy mineral HS concentrates, sample 90-18 988

#	Grain	Association	Type	Mineral	Area, µm2	ECD, µm
1	40-10	vsl-Au_3Cu-bn	bms	Total	324	20.3
2	40-10	vsl-Au_3Cu-bn	bms	Au_3Cu	12	3.9
3	40-10	vsl-Au_3Cu-bn	bms	vsl	312	19.9
4	40-11	Au_3Cu	L	Au_3Cu	180	15.1
5	40-12	vys-bn	bms	vys	106	11.6
6	40-13	vys-bn	bms-L	vys	1578	44.8
7	40-14	vys-bn	bms	vys	99	11.2
8	40-15	kth-bn	bms	kth	42	7.3
9	40-16	vys-bn	bms	vys	49	7.9
10	40-17	Au_3Cu	L	Au_3Cu	153	14
11	40-18	vys-bn	bms	vys	92	10.8
12	40-19	vys-bn	bms	vys	131	12.9
13	40-1	vsl-bn-chc	bms	vsl	29	6.1
14	40-20	gng-bn	bms	gng	18	4.8
15	40-21	vys-bn-chl	sag	vys	285	19.1
16	40-22	$(Pd,Ag)_5S$-CdS-bn	bms	un	13	4.1
17	40-23	vsl-bn	bms	vsl	54	8.3
18	40-24	vsl-kth-Au_3Cu	L+	Total	293	19.3
19	40-24	vsl-kth-Au_3Cu	L+	Au_3Cu	37	6.9
20	40-24	vsl-kth-Au_3Cu	L+	kth	34	6.6
21	40-24	vsl-kth-Au_3Cu	L+	vsl	222	16.8
22	40-24	vsl-kth-Au_3Cu	L+	vsl	10	3.6
23	40-25	vys-bn	bms	vys	56	8.4
24	40-2	vsl-bn	bms	vsl	14	4.2
25	40-3	sk-nls-bn-chc	bms-L	Total	490	25
26	40-3	sk-nls-bn-chc	bms-L	nls	160	14.3
27	40-3	sk-nls-bn-chc	bms-L	sk	330	20.5
28	40-4	un1-zv-bn	bms	Total	99	11.2
29	40-4	un1-zv-bn	bms	un1	80	10.1
30	40-4	un1-zv-bn	bms	zv	19	4.9
31	40-5	(Au,Cu,Ni,Zn)	L	(Au,Cu,Ni,Zn)	620	28.1
32	40-6	vys-CdS-bn	bms	vys	12	3.9
33	40-7	gng-chc-bn	bms	gng	41	7.2
34	40-8	vys-bn	bms	vys	440	23.7
35	40-9	vys-bn	bms	vys	18	4.8
36	70-1	vys-bn	bms	vys	147	13.7
37	70-1	vys-bn	bms	vys	17	4.7
38	70-1	vys-bn	bms	vys	10	3.6
39	100-1	vys-bn	bms	vys	187	15.4
40	100-2	vys-bn	bms	vys	100	11.3
41	100-3	vys-bn	bms	vys	95	11
42	100-4	gng-zv-Au_3Cu-bn	bms	Total	28	6
43	100-4	gng-zv-Au_3Cu-bn	bms	gng	10	3.6
44	100-4	gng-zv-Au_3Cu-bn	bms	gng	5	2.5
45	100-4	gng-zv-Au_3Cu-bn	bms	zv	5	2.5
46	100-4	gng-zv-Au_3Cu-bn	bms	Au_3Cu	8	3.2

Abbreviations: VSL: vasilite; bn: bornite; vys: vysotskite; chc: chalcocine; gng: guanglinite; kth: keithconnite; sk: skaergaardite; nls: nielsenite: un1: unknown 1.
See Table 5 for explanation of association types.

Table 5 **Liberation of precious metal minerals (with ECD) in the heavy mineral HS concentrates, Sample 90-18 988**

#	Association	n	Area, µm2	#%	area%	ECDmin	ECDavg	ECDmax
1	bms	25	2232	75.8	38.2	3.6	9.4	23.7
2	bms-L	2	2068	6.1	35.4	25	34.9	44.8
3	sag	1	285	3	4.9		19.1	
4	L	3	953	9.1	16.3	14	15.1	28.1
5	L+	2	303	6.1	5.2	3.6	11.4	19.3
	Total	33	5841	100	100			

Abbreviations:

Bms: Intergrowths of PGMs with base metal sulphides (bornite, chacocine, chalcopyrite);
bms-L: liberated particles with<10% attached base metal sulphides;
sag: intergrowths of PGM with base metal sulphides and gangue;
L: liberated (free) particles of precious metal minerals;
L+: completely liberated (free) particles of two or more precious metal minerals

Comment: Grain sizes in microns (µm)

Table 6. **Chemical compositions (wt.%) and formuli of vysotskite from the heavy mineral HS concentrates, sample 90-18 988**

Analysis #	Grain #	Association	analysis							*cations*					
			Pd	Pt	Cu	Fe	Ni	S	Total	Pd	Pt	Cu	Fe	Ni	S
1	40-6	vys+CdS+bn	65.3	0.0	8.6	1.2	0.0	24.2	99.3	*0.80*	*0.00*	*0.18*	*0.03*	*0.00*	*0.99*
2	40-8	vys+bn	75.7	0.0	0.4	0.4	0.0	23.2	99.7	*0.98*	*0.00*	*0.01*	*0.01*	*0.00*	*1.00*
3	40-12	vys+bn	74.0	1.9	0.4	0.7	0.0	23.1	100.2	*0.96*	*0.01*	*0.01*	*0.02*	*0.00*	*1.00*
4	40-13	vys+bn	76.0	0.0	0.3	0.0	0.0	23.1	99.5	*0.99*	*0.00*	*0.01*	*0.00*	*0.00*	*1.00*
5	40-14	vys+bn	72.0	1.3	1.8	1.0	0.0	23.5	99.5	*0.93*	*0.01*	*0.04*	*0.02*	*0.00*	*1.00*
6	40-18	vys1,2-bn	66.8	3.6	1.0	0.0	5.0	23.9	100.2	*0.84*	*0.02*	*0.04*	*0.00*	*0.11*	*1.00*
7	40-18	vys1,2-bn	48.2	22.5	1.1	0.9	2.5	21.1	99.4	*0.69*	*0.20*	*0.03*	*0.03*	*0.06*	*1.00*
8	40-19	vys-bn	73.4	0.0	1.6	0.8	0.0	23.6	99.4	*0.94*	*0.00*	*0.03*	*0.02*	*0.00*	*1.00*
9	40-21	vys-bn-chl	74.8	0.0	0.9	0.0	0.0	23.6	99.3	*0.97*	*0.00*	*0.02*	*0.00*	*0.00*	*1.01*
10	70-1	vys-bn	73.0	0.0	2.2	0.6	0.5	23.6	99.9	*0.93*	*0.00*	*0.05*	*0.01*	*0.01*	*1.00*
11	100-1	vys-bn	74.3	0.0	1.7	0.0	0.0	23.4	99.4	*0.96*	*0.00*	*0.04*	*0.00*	*0.00*	*1.00*
12		average	70.3	2.7	1.8	0.5	0.7	23.3	99.6	*0.91*	*0.02*	*0.04*	*0.01*	*0.02*	*1.00*

Abbreviations: vys: vysotskite; bn: bornite; chl: chlorite

Table 7 **Chemical compositions (wt.%) and cation proportions of vasilite from the heavy mineral HS concentrates, sample 90-18 988**

#	Grain #	Association	**analysis** Pd	Cu	Fe	S	Total	***cations*** *Pd*	*Cu*	*Fe*	*S*
1	40-1	vsl+bn+chc	72.60	13.60	0.80	12.80	99.70	*11.99*	*3.77*	*0.24*	*7.00*
2	40-2	vsl+bn	71.90	13.50	1.50	12.80	99.70	*11.63*	*3.79*	*0.47*	*6.99*
3	40-10	Vsl+Au_3Cu+bn	72.50	13.90	0.40	12.70	99.50	*12.02*	*3.86*	*0.13*	*6.99*
4	40-23	vsl-bn	73.90	11.90	1.00	12.60	99.40	*12.36*	*3.33*	*0.32*	*6.99*
5	40-24	Vsl+kth+Au_3Cu+bn	72.70	13.00	0.80	12.70	99.20	*12.10*	*3.62*	*0.25*	*7.02*
6	100-2	vsl-bn	72.00	13.70	0.70	12.70	99.10	*11.98*	*3.81*	*0.23*	*6.98*
7		average	72.60	13.30	0.90	12.70	99.50	*12.01*	*3.70*	*0.27*	*7.00*

Abbreviations: vsl: vasilite; bn: bornite; chc: chalcocine; kth: keithconnite

Table 8: Chemical compositions (wt.%) and formulas of skaergaardite and nielsenite, sample 90-18 988

Grain #	**40-3**	**40-3**
Mineral	**skaergaardite**	**nielsenite**
Association	**sk+nls+bn**	**sk+nls+bn**
Analysis		
Pd	55.8	35.6
Pt	2.1	
Au	5.1	
Cu	30.9	63.3
Fe	2.5	1.0
Zn	3.4	
Total	99.8	99.9
atomic proportions		
Pd	*0.92*	*0.99*
Pt	*0.02*	
Au	*0.05*	
Cu	*0.85*	*2.95*
Fe	*0.08*	*0.05*
Zn	*0.09*	
cations	2.01	3.99

abbreviations: sk: skaergaardite; nls: nielsenite; bn: bornite

Table 9: Chemical compositions (wt.%) and formulas of (Au-Cu) alloys, sample 90-18 988

Grain#	40-10	40-11	40-17	40-24	average	40-5
Mineral	Un-named **Au3Cu**	Un-named **Au3Cu**	Un-named **Au3Cu**	Un-named **Au3Cu**	Un-named **Au3Cu**	Un-named **(Cu,Au,Ni,Zn) alloy**
Association	vsl+Au_3Cu+bn	Au_3Cu	Au_3Cu	vsl-kth-Au_3Cu-bn		(Cu,Au,Ni,Zn)
Analysis						
Pd	16.8	16.9	20.0	17.9	17.9	
Pt	0.0	0.0	0.0	18.6	4.7	
Au	66.0	72.0	67.9	51.7	64.4	59.8
Ag	2.2					2.0
Cu	13.4	9.4	11.6	8.4	10.7	24.1
Fe	1.3	1.1	0.9	2.7	1.5	0.3
Zn						5.8
Ni						7.6
Total	99.8	99.4	100.4	99.3	99.7	99.6
atomic proportions						
Pd	*0.86*	*0.92*	*1.03*	*0.95*	*0.94*	
Pt	*0.00*	*0.00*	*0.00*	*0.54*	*0.14*	
Au	*1.81*	*2.11*	*1.89*	*1.49*	*1.83*	*0.33*
Ag	*0.06*	*0.00*	*0.00*	*0.00*	*0.02*	*0.01*
Cu	*1.14*	*0.86*	*1.00*	*0.75*	*0.94*	*0.41*
Fe	*0.13*	*0.11*	*0.09*	*0.27*	*0.15*	*0.01*
Zn						*0.10*
Ni						*0.14*
Cations	4.00	4.00	4.01	4.00	4.02	1.00

Abbreviations: vsl: vasilite; bn: bornite; kth: keithconnite;

Table 10: Chemical compositions (wt.%) and formulas of guanglinite, zvyagintsevite and keithconnite, sample 90-18 988

Analysis #	1	2	3	4	5	6
Grain #	40-7	40-15	40-20	average	40-4	40-24
Mineral	Guanglinite	Guanglinite	Guanglinite	Guanglinite	Zvyagintsevite	Keithconnite
Association	gng+chc+bn	gng+bn	gng-bn		UN1+zv+bn	vsl-kth-Au3Cu-bn
Analusis						
Pd	68.2	68.3	76.1	70.9	66.5	67.3
Cu	4.1	3.3	2.1	3.2	2.1	
Fe	0.7	0.9	0.0	0.5	1.0	0.7
Sn	0.0	2.8	6.0	2.9	1.6	
Te	11.8	10.0	7.4	9.7	0.0	31.4
Pb	6.4	7.2	0.0	4.5	28.7	
As	8.1	6.6	8.1	7.6	0.0	
Total	99.3	99.1	99.8	99.3	99.9	99.4
atomic proportions						
Pd	*2.70*	*2.75*	*2.96*	*2.80*	*3.02*	*2.84*
Cu	*0.27*	*0.22*	*0.14*	*0.21*	*0.16*	
Fe	*0.05*	*0.07*	*0.00*	*0.04*	*0.09*	*0.06*
Sn	*0.00*	*0.10*	*0.21*	*0.10*	*0.07*	
Te	*0.39*	*0.34*	*0.24*	*0.32*	*0.00*	*1.10*
Pb	*0.13*	*0.15*	*0.00*	*0.09*	*0.67*	
As	*0.45*	*0.38*	*0.45*	*0.43*	*0.00*	
cations	*3.99*	*4.01*	*4.00*	*3.99*	*4.01*	4.00

Abbreviations: gng: guanglinite; chc: chalcocine; bn: bornite; zv: zvyagintsevite; kth: keithconnite,

Table 11. **Chemical compositions (wt.%) and formuli of un-named (Pd,Ag)5S, (Pd,Ag,Cd,Cu,Tl)4S, and Pd-Ag bearing CdS, sample 90-18 988**

Analysis#	1	2	3
Grain#	40-22	40-4	40-22
Mineral or phase	Un-named (Pd,Ag)5S	Un-named (Pd,Ag,Cd,Cu,Tl)4S	Un-named Pd-, Ag-bearing CdS
Association	$(Pd,Ag)_5S$+CdS+bn	$(Pd,Ag,Cd,Cu,Tl)_4S$+zv+bn	$(Pd,Ag)_5S$+CdS+bn
analysis			
Pd	55.1	58.8	3.8
Cu	1.0	3.2	3.3
Fe		0.8	1.4
Zn		0.0	3.9
S	5.7	6.4	23.8
Tl		6.9	
Ag	37.5	15.4	3.4
Cd		7.8	60.1
Total	99.3	99.3	99.6
atomic proportions			
Pd	*2.93*	*2.77*	*0.05*
Cu	*0.09*	*0.25*	*0.07*
Fe		*0.07*	*0.03*
Zn		*0.00*	*0.08*
S	*1.00*	*1.00*	*1.00*
Tl		*0.17*	
Ag	*1.97*	*0.39*	*0.04*
Cd		*0.35*	*0.72*
Total	*6.00*	*5.00*	*2.00*

Abbreviations: bn: bornite; zv: zvyagintsevite

Plates

Plate 1

The relationship of rock-forming minerals, Fe-Ti oxides and sulphides in the tholeitic gabbros of the sample 90-18 988 (1-4), polished section, SEM images (BIE); abbreviations used: pl – plagioclase, cpx – clinopyroxene, opx – orthopyroxene, cpx-opx exs – clinopyroxene-orthopyroxene exsolution texture, ol – olivine, ilm - ilmenite, timt – titaniferous magnetite, bn – bornite.

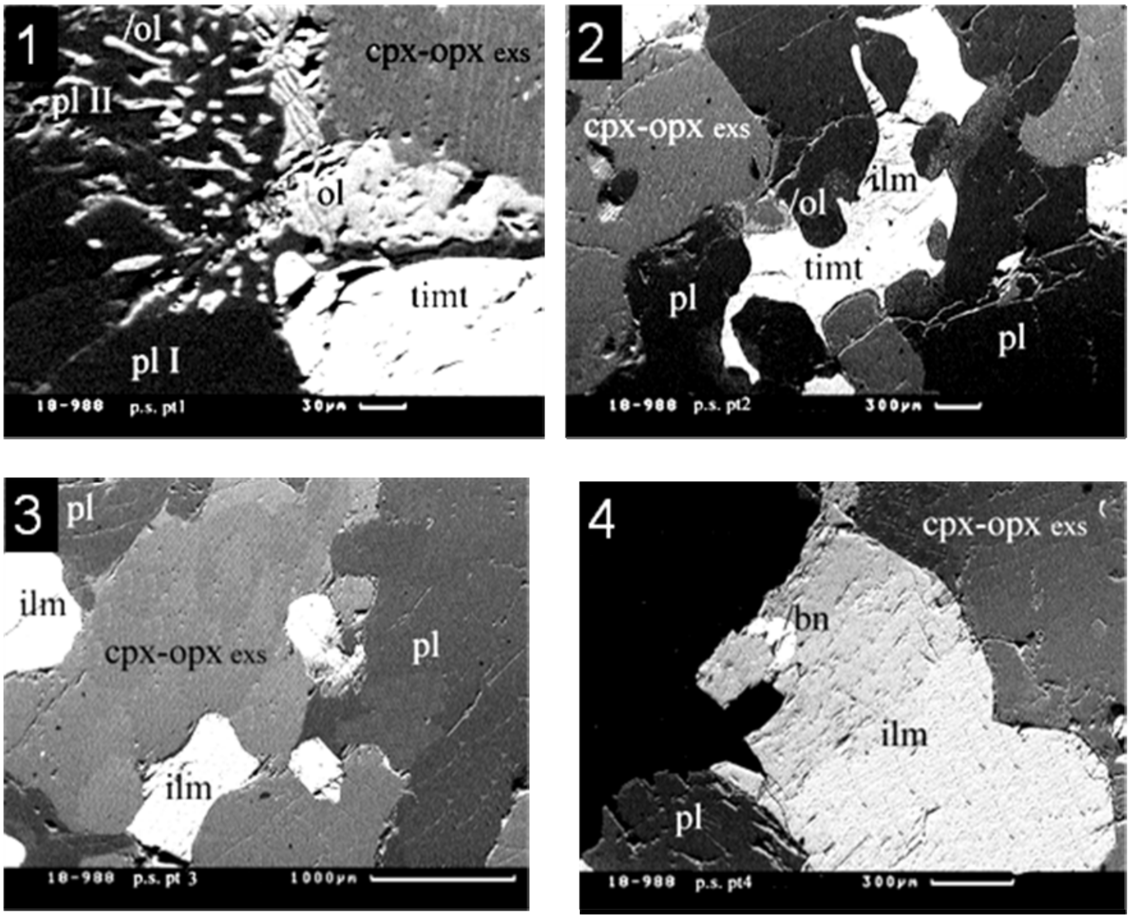

1
/ol
pl II
cpx-opx exs
ol
timt
pl I
10-988 p.s. pt1 30µm
2
cpx-opx exs
ilm
/ol
timt
pl
pl
10-988 p.s. pt2 300µm
3
pl
ilm
cpx-opx exs
pl
ilm
10-988 p.s. pt 3 1000µm
4
cpx-opx exs
/bn
ilm
pl
10-988 p.s. pt4 300µm

Plate 2

Polished sections of the heavy mineral HS concentrates (1 -fraction <40 µm; 2 – 50-70 µm, 3 – 70-100 µm, sample 18-988), SEM-images (BIE); abbreviations used: ilm – ilmenite, vys – vysotskite, bn – bornite, chc – chalcosine, opx – orthopyroxene.

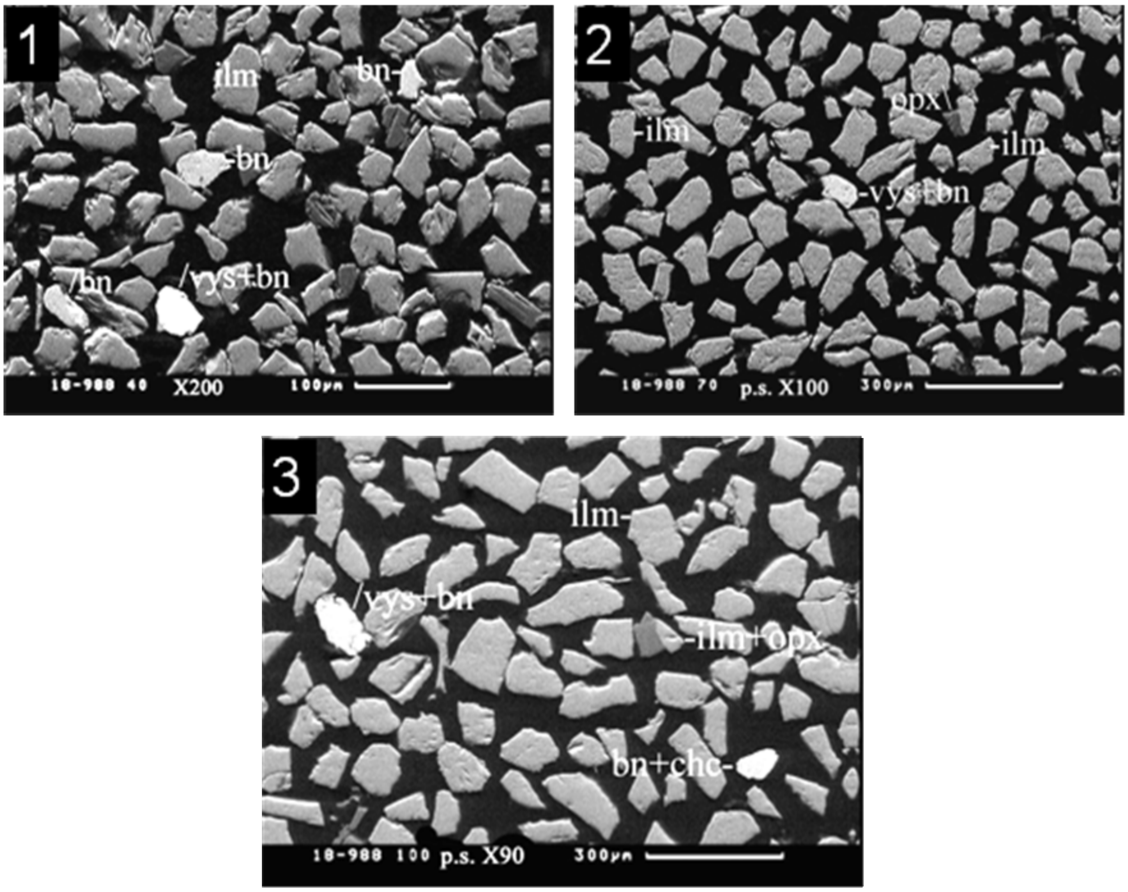
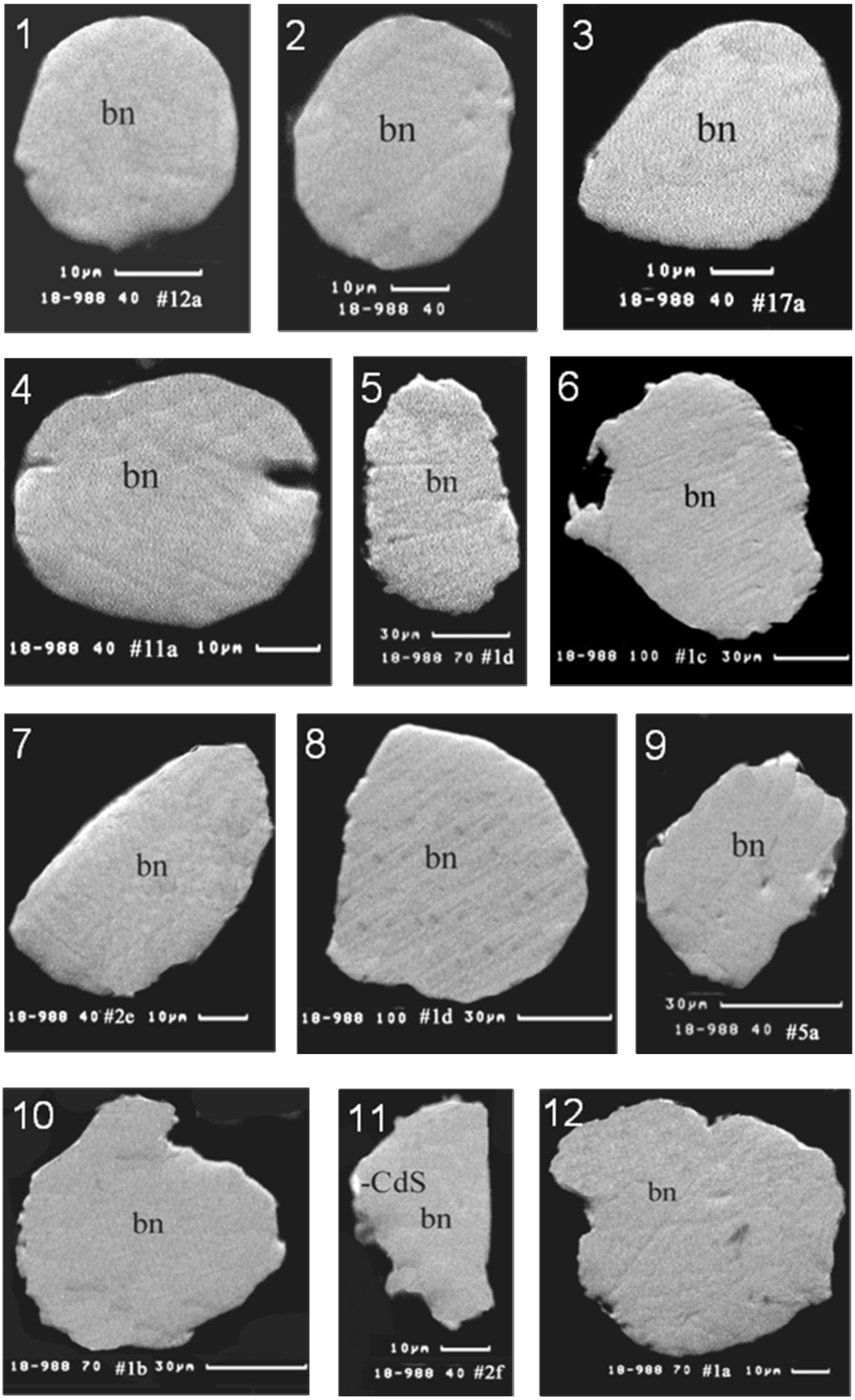
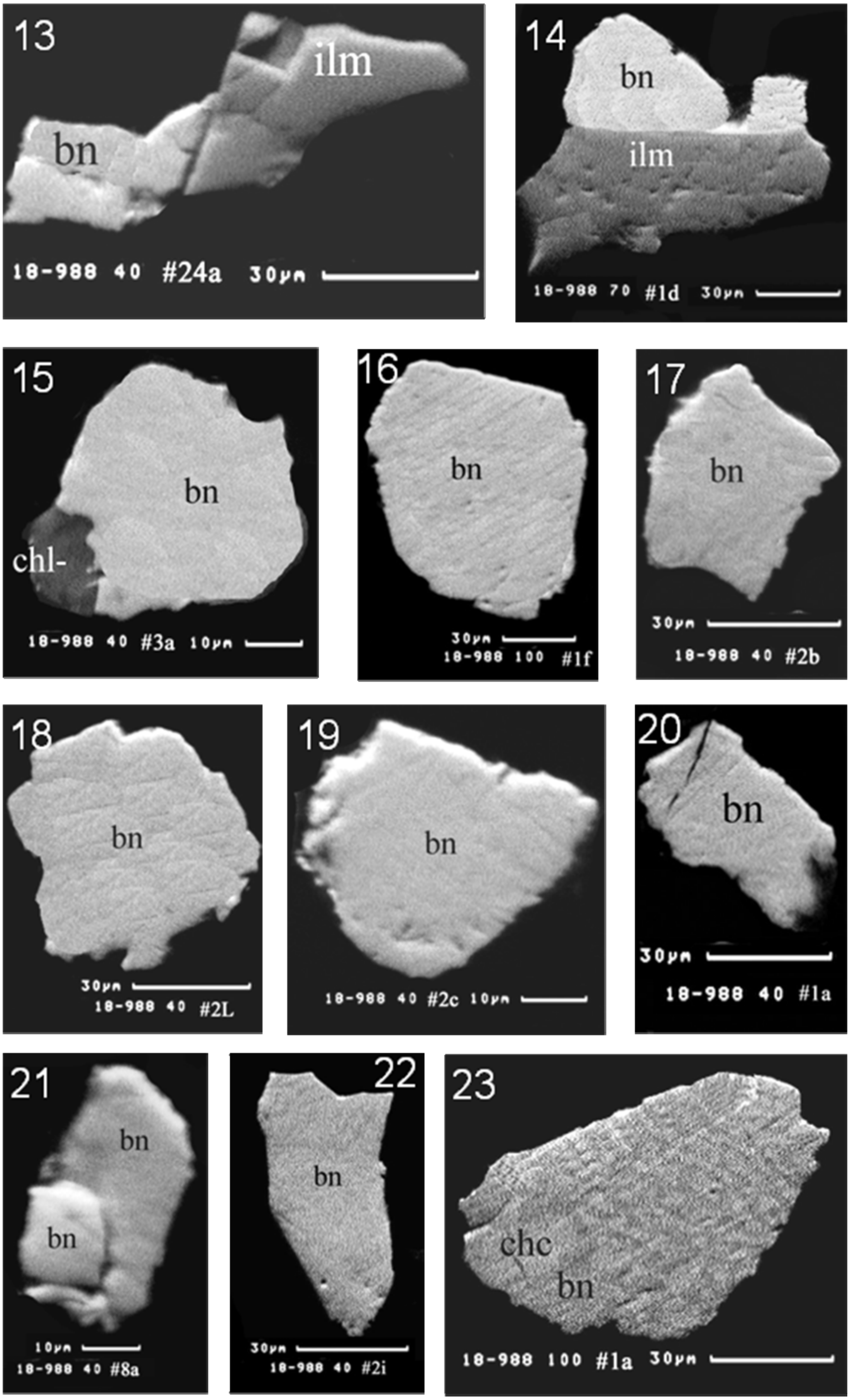

1
ilm
bn-
-bn
/bn
/vys+bn
10-988 40
X200
100µm
2
opx
-ilm
-ilm
-vys+bn
10-988 70
p.s. X100
300µm
3
ilm-
/vys+bn
-ilm+opx
bn+chc-
10-988 100
p.s. X90
300µm

Plate 3

Sulphide mineralisation globules and grains of oxide rich tholeitic gabbros, sample 18-988 (1-31); polished sections; SEM-images (BIE); abbreviations used: bn – bornite, cp – chalcopyrite, chc – chalcosine, ilm – ilmenite, chl – chlorite. CdS is cadmium sulfide.


1
bn
10μm
18-988 40 #12a
2
bn
10μm
18-988 40
3
bn
10μm
18-988 40 #17a
4
bn
18-988 40 #11a 10μm
5
bn
30μm
18-988 70 #1d
6
bn
18-988 100 #1c 30μm
7
bn
18-988 40 #2c 10μm
8
bn
18-988 100 #1d 30μm
9
bn
30μm
18-988 40 #5a
10
bn
18-988 70 #1b 30μm
11
-CdS
bn
10μm
18-988 40 #2f
12
bn
18-988 70 #1a 10μm


13
ilm
bn
18-988 40 #24a 30µm
14
bn
ilm
18-988 70 #1d 30µm
15
bn
chl-
18-988 40 #3a 10µm
16
bn
30µm
18-988 100 #1f
17
bn
30µm
18-988 40 #2b
18
bn
30µm
18-988 40 #2L
19
bn
18-988 40 #2c 10µm
20
bn
30µm
18-988 40 #1a
21
bn
bn
10µm
18-988 40 #8a
22
bn
30µm
18-988 40 #2i
23
chc
bn
18-988 100 #1a 30µm

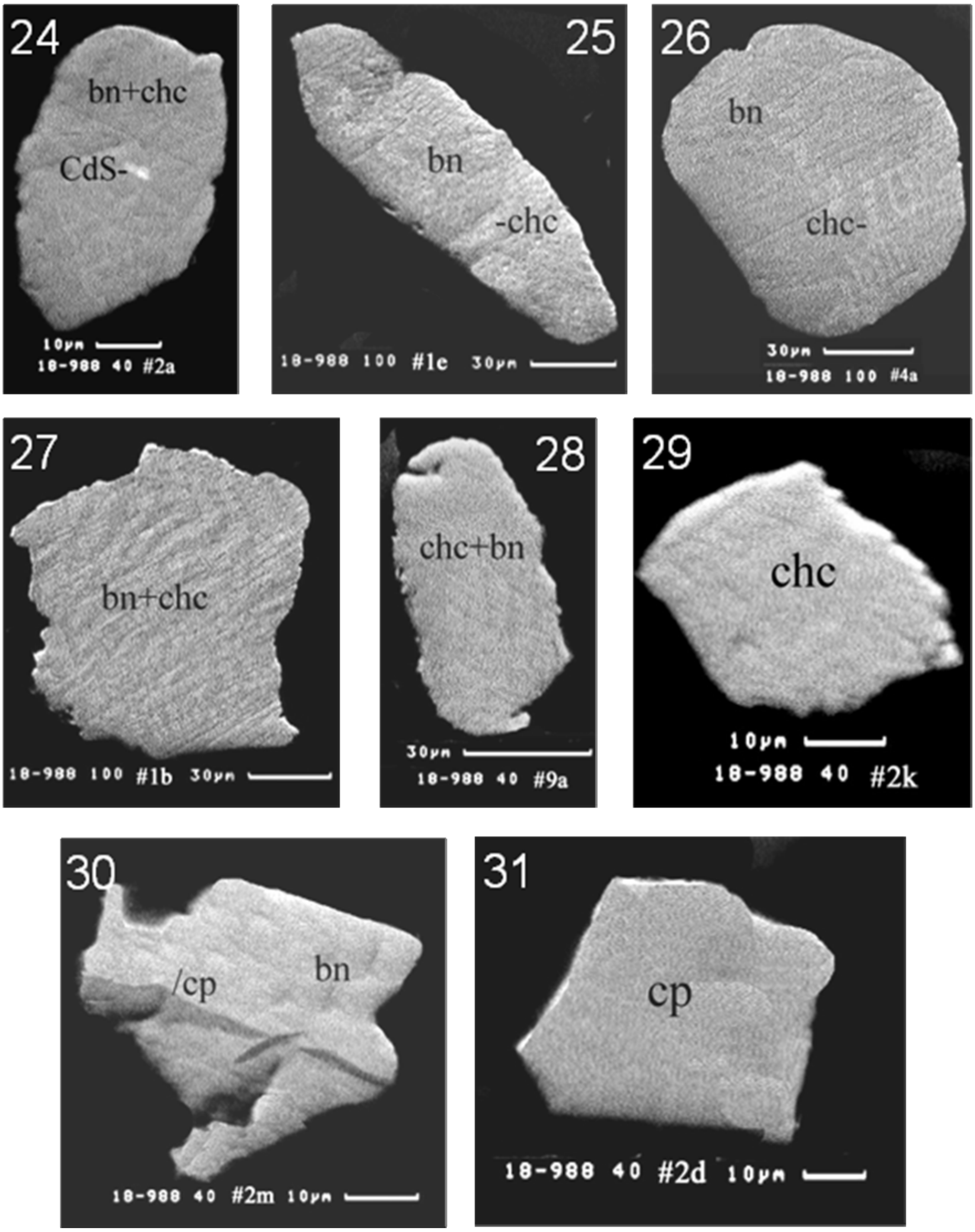
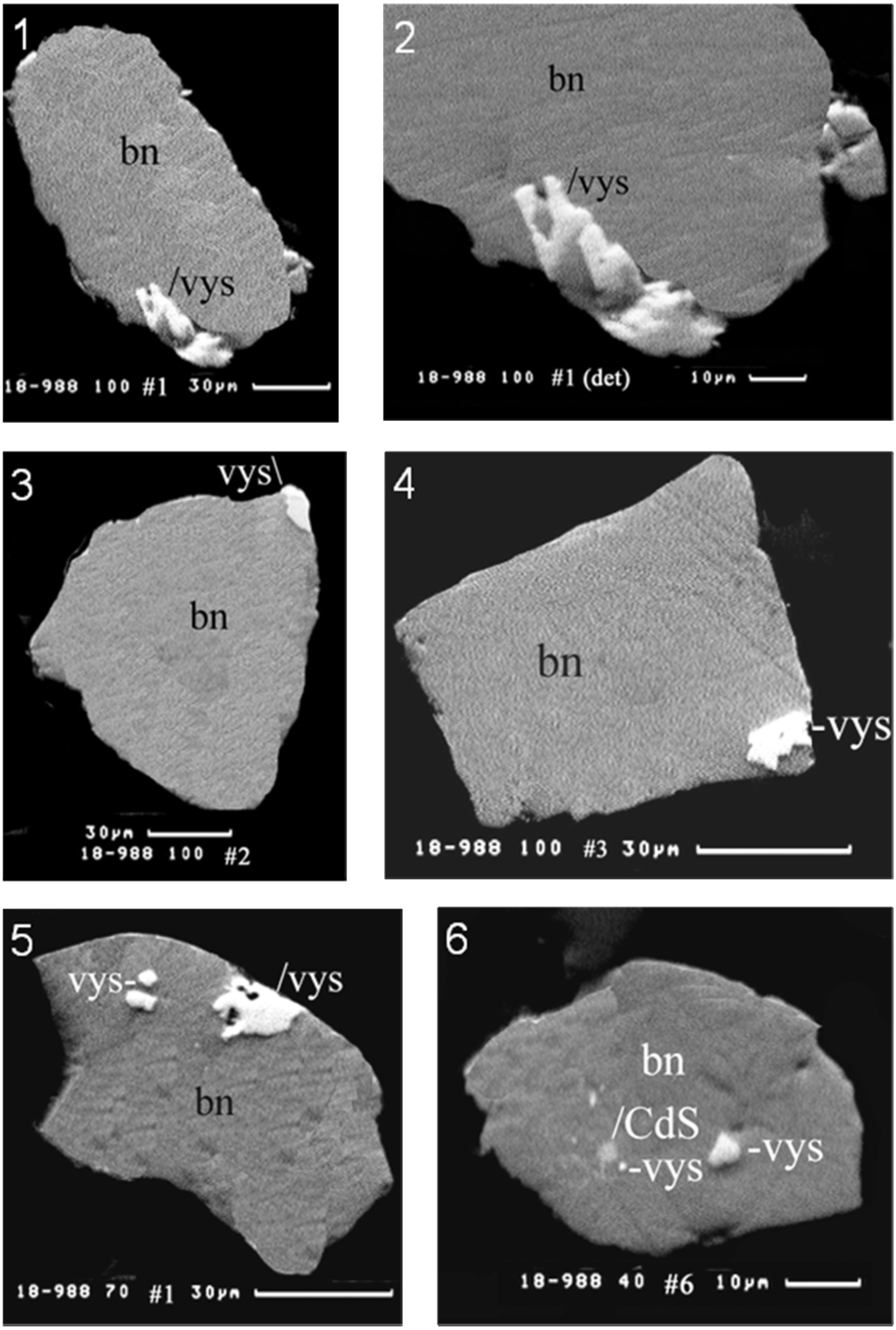
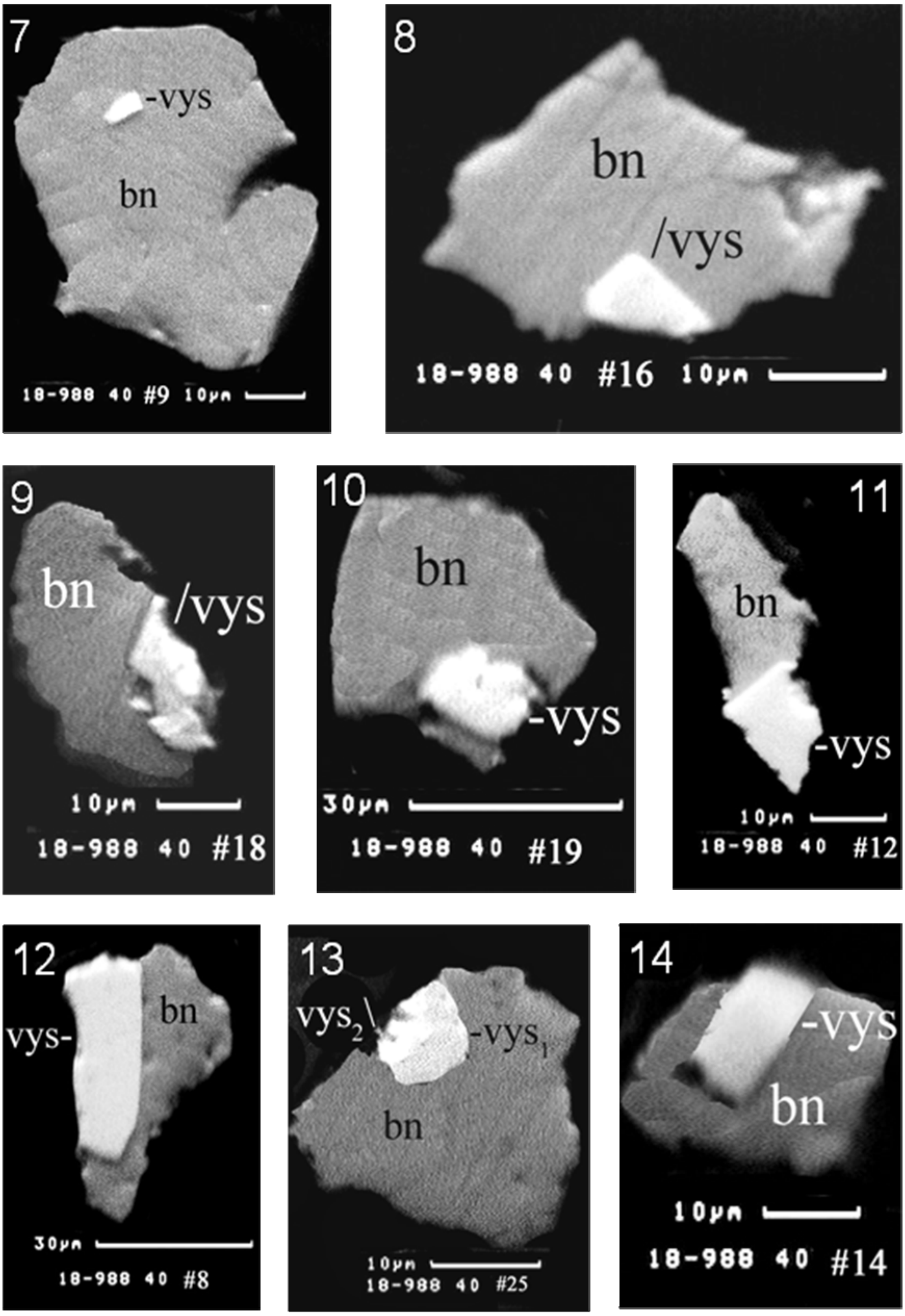
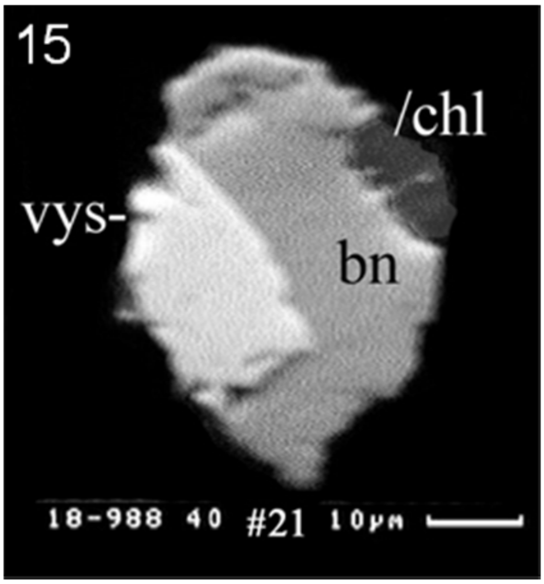

24
bn+chc
CdS-
10µm
18-988 40 #2a
25
bn
-chc
18-988 100 #1e 30µm
26
bn
chc-
30µm
18-988 100 #4a
27
bn+chc
18-988 100 #1b 30µm
28
chc+bn
30µm
18-988 40 #9a
29
chc
10µm
18-988 40 #2k
30
/cp
bn
18-988 40 #2m 10µm
31
cp
18-988 40 #2d 10µm

Plate 4

SEM-images (BIE) of vysotskite (1-16) from the polished sections of the heavy mineral HS concentrates of the sample 90-18 988; 2 is detail of 1; abbreviations used vys – vysotskite, bn – bornite, cp – chalcopyrite, chl – chlorite. CdS is cadmium sulfide.


1
bn
/vys
18-988 100 #1 30μm
2
bn
/vys
18-988 100 #1 (det) 10μm
3
vys\
bn
30μm
18-988 100 #2
4
bn
-vys
18-988 100 #3 30μm
5
vys-
/vys
bn
18-988 70 #1 30μm
6
bn
/CdS
-vys
-vys
18-988 40 #6 10μm


7
-vys
bn
18-988 40 #9 10µm
8
bn
/vys
18-988 40 #16 10µm
9
bn
/vys
10µm
18-988 40 #18
10
bn
-vys
30µm
18-988 40 #19
11
bn
-vys
10µm
18-988 40 #12
12
vys-
bn
30µm
18-988 40 #8
13
vys2\
-vys1
bn
10µm
18-988 40 #25
14
-vys
bn
10µm
18-988 40 #14


15
/chl
vys-
bn
18-988 40 #21 10μm

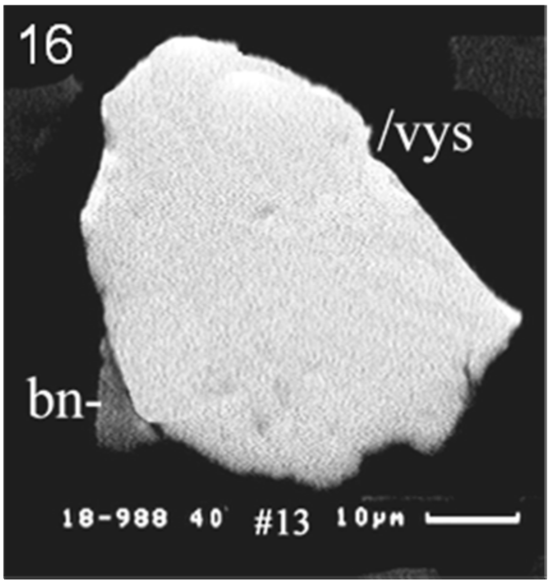

16
/vys
bn-
18-988 40 #13 10μm

Plate 5

SEM-images (BIE) of vasilite (1-3) from the polished sections of the heavy mineral HS concentrates of the sample 90-18 988; abbreviations used: vsl - vasilite, bn – bornite, cp – chalcopyrite.

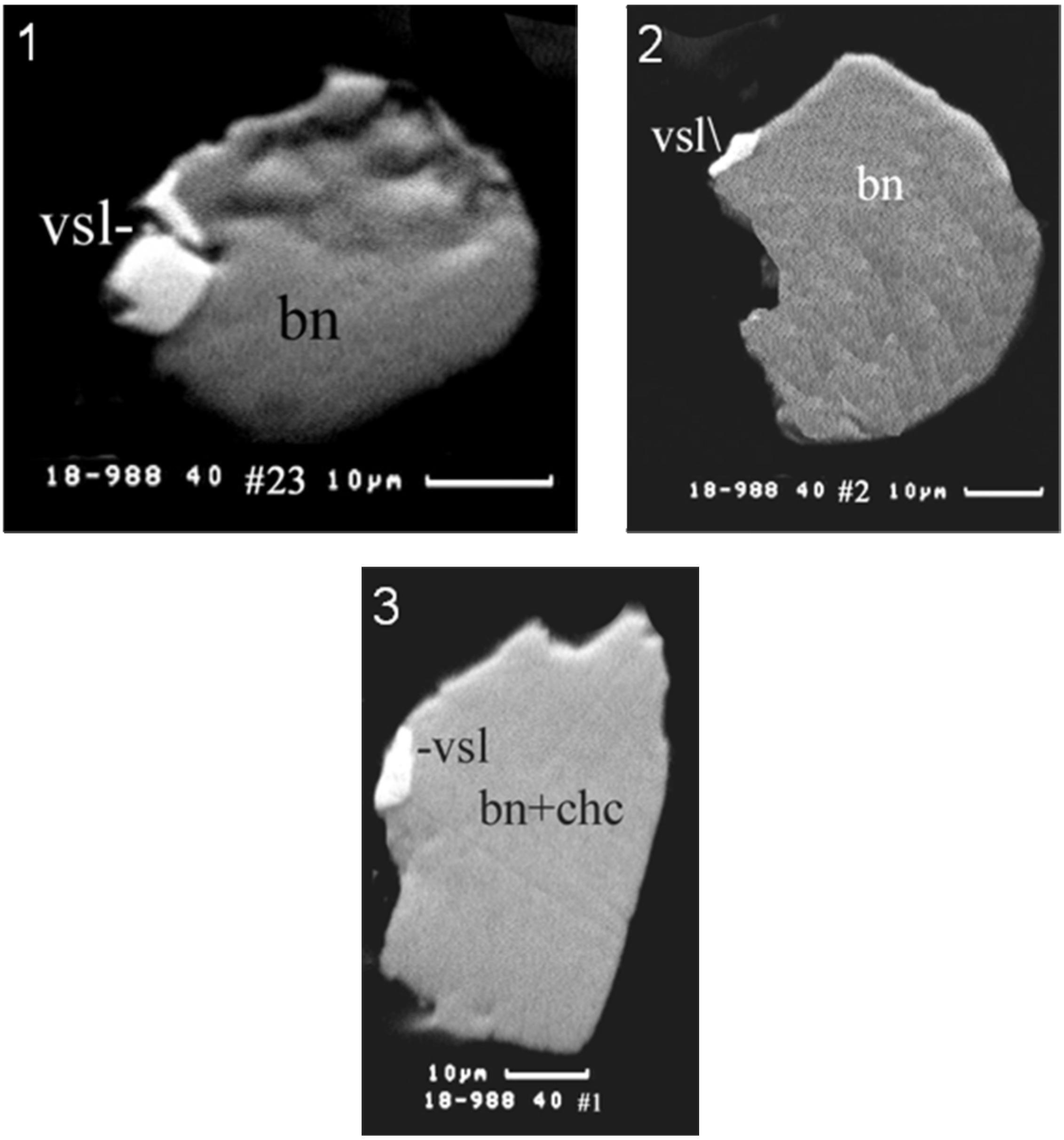

1
vsl-
bn
18-988 40 #23 10μm
2
vsl\
bn
18-988 40 #2 10μm
3
-vsl
bn+chc
10μm
18-988 40 #1

Plate 6

SEM-images (BIE) of (Au,Cu) alloys (1-6), vasilite (vsl; 1, 3), guanglinite (gng, 2), zvyagintsevite (zv, 2) and keithconnite (kth; 3) from the polished sections of the heavy mineral HS concentrates of the sample 18-988; bn – bornite, cp – chalcopyrite.

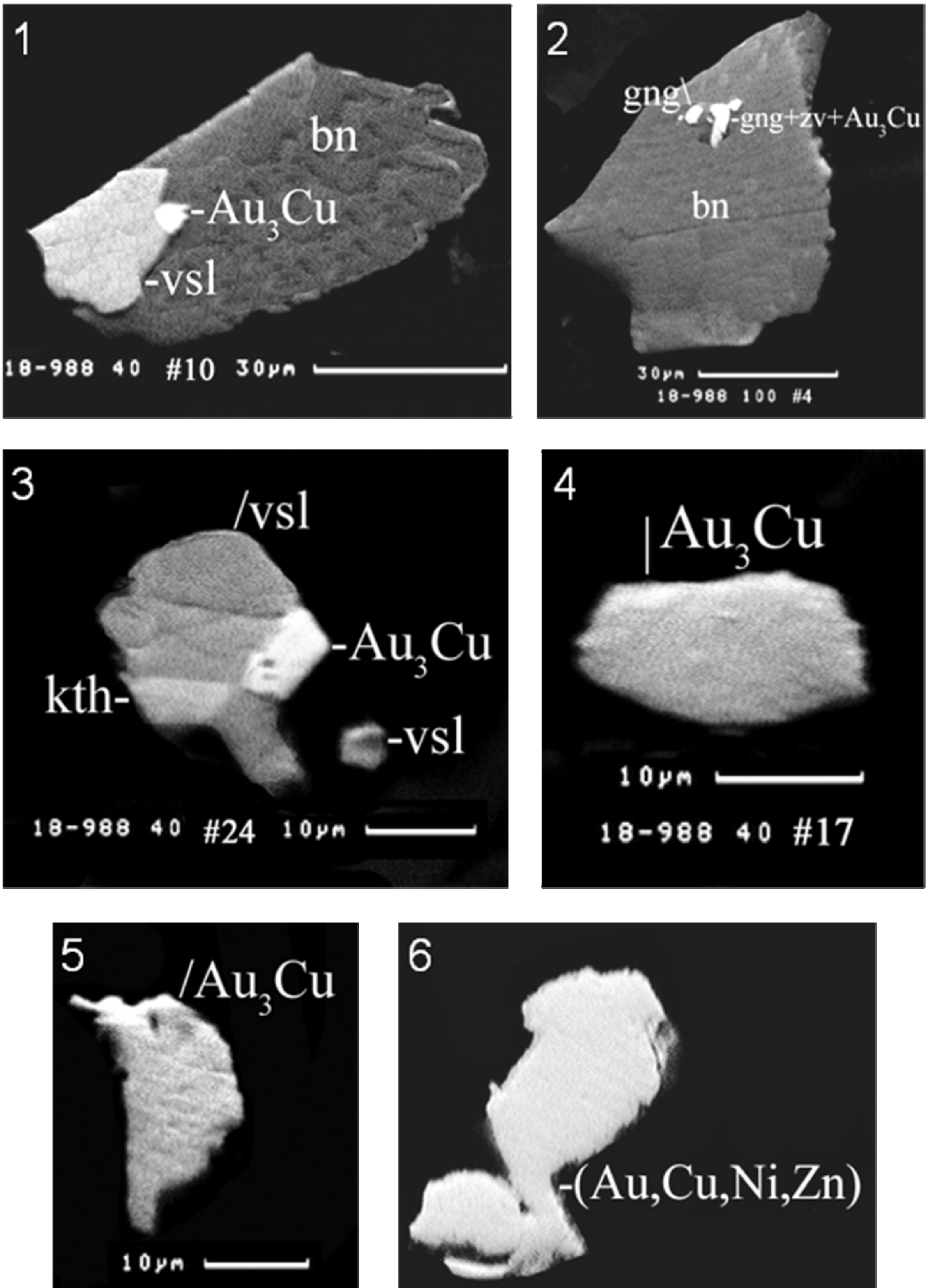
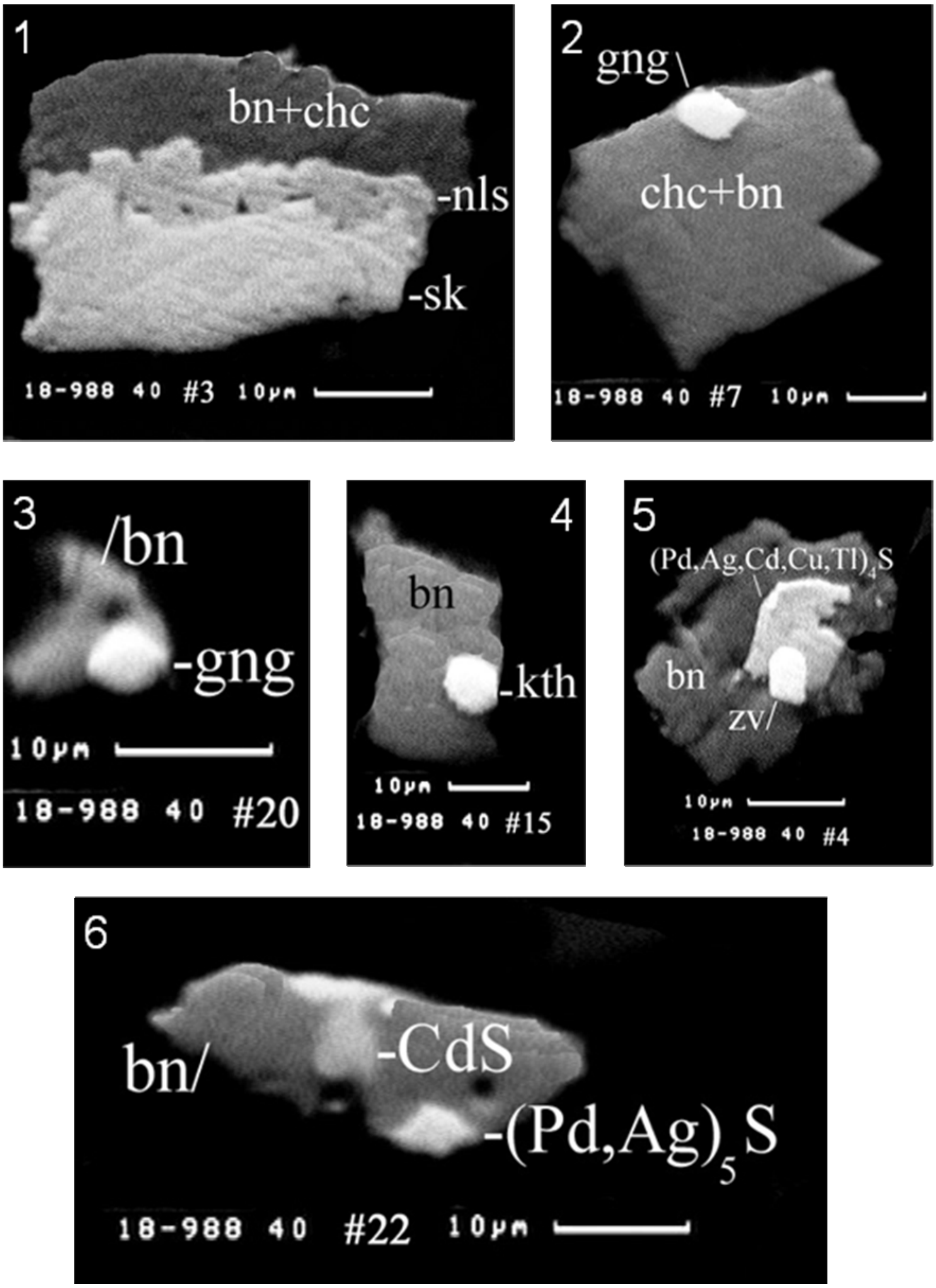

1
bn
-Au3Cu
-vsl
18-988 40 #10 30μm
2
gng
-gng+zv+Au3Cu
bn
30μm
18-988 100 #4
3
/vsl
-Au3Cu
kth-
-vsl
18-988 40 #24 10μm
4
Au3Cu
10μm
18-988 40 #17
5
/Au3Cu
10μm
18-988 40 #11
6
-(Au,Cu,Ni,Zn)
18-988 40 #5 10μm

Plate 7

SEM image (BIE) of skaergaardite (sk; 1) and nielsenite (nls; 1), guanglinite (gng; 2, 3), keithconnite (kth; 4), zvyagintsevite, (zv; 5), un-named (Pd,Ag,Cd,Cu,Tl)4S (6), and un-named (Pd,Ag)5S (7) from the polished sections of heavy HS mineral concentrates from sample 90-18 988; bn: bornite; chc: chalcocine. CdS is cadmium sulfide.


1
bn+chc
-nls
-sk
18-988 40 #3 10μm
2
gng
chc+bn
18-988 40 #7 10μm
3
/bn
-gng
10μm
18-988 40 #20
4
bn
-kth
10μm
18-988 40 #15
5
$(Pd,Ag,Cd,Cu,Tl)_4S$
bn
zv/
10μm
18-988 40 #4
6
bn/
-CdS
$-(Pd,Ag)_5S$
18-988 40 #22 10μm