DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/95

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

Part 16: Sample 90-10 445

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Abstract

The report presents the results of a mineralogical investigations of the sample 90-10 445 from the Pd5 level in the Skaergaard mineralisation. The sample collects the interval between 445.0 and 446.0 m in core 90-10. Assays give 2491 ppb Pd, 142 ppb Au, and 129 ppb Pt for the interval.

The 557g sample was crushed in small portions using a shatter box with small cavities (200 ml) for short periods (0.3-0.5 min), sieved to remove the fine fraction (sieve - 125 μm) after each crushing session. The residual coarse fraction >125 μm was re-crushed until the entire sample had attained the desired maximum grain size. After complete crushing the material was sieved into the following fractions: 1) <40, 2) 40-70, 3) 70-125 μm. All fractions were then subjected to wet magnetic separation. None of the magnetic fractions proved to contain grains of precious metal minerals.

The non-magnetic concentrates of every fraction were density separated using the computer controlled hydroseparator CNT-HS-11. Monolayer polished sections were produced for each grain size fraction from the heavy mineral HS-concentrates. The polished sections and one polished section of a chip from the core were investigated under the scanning electron microscope and the electron microprobe.

The host rock shows the characteristic characteristic reaction relationship between cumulus and intercumulus phases including rims of olivine at the boundaries between Fe-Ti-oxides and clinopyroxene with orthopyroxene exsolutions. In general, it is a relatively “dry” rock with only very local occurrence of H_2O-bearing minerals. The reaction rims of olivine are partly replaced by serpentine and magnetite aggregates. In addition, H_2O-bearing minerals occur in very insignificant amounts in intergrowths with Cu-Fe-sulphides and PGMs.

The HS-concentrates contain numerous sulphide grains identified as sulphide droplets. They are composed of one or two sulphides - bornite, chalcopyrite, sometimes of pentlandite, chalcosine, digenite and pyrrhotite. Some of these droplets and sulphide grains contain inclusions of PGMs.

Three grains of zircon - one of them with thorionite inclusion - as well as one uraninite particle were identified in the heavy mineral concentrates. The occurrence of these phases in the sample opens for the possibility for geochronologicaland isotopic investigations.

Twenty-three PGM-bearing particles were selected for more detailed investigation The investigation showed that the main PGMs are: (1) vasilite $(Pd,Cu)_{17}S_6$ (45.4 %), (2) guanglinite $(Pd,Pt)_3(As,Sn)$ (30.3 %) and (3) vysotskite (Pd,Ni,Cu,Fe)S (19.1%). Less common (in total app. 5 area %) are: (4) atokite Pd_3Sn (2.6 %), (5) unnamed $Pd_{11}As_2Sn_2$ (1.9 %), (6) skaergaardite (Pd,Au,Pt)(Cu,Fe,Zn) (0.5 %), (7) (Pt,Fe,Cu) alloy (0.2 %), and (8) zvyagint-

sevite $Pd_3(Pb,Sn)$ (<0.1 %). The grain size of the PGMs (ECD) varies between 1 and 29 μm with an average of 14 μm.

The PGM paragenesis is entirely dominated by PGE sulphides (vasilite and vysotskite) and arsenides (guanglinite) are dominating; Pt is found as inclusions of (Pt,Fe) alloy in the guanglinite and skaergaardite. No Au minerals were found and Au occurs apparently only as substitution in composition of skaergaardite.

All the observations and the inter-grain relations suggest that all the PGMs are part of the a single paragenesis. The most noticeable PGM observation is the occurrence of PGM droplets in base metal sulphide droplets. This is strong indication for the occurrence of two immiscible melts: 1) Cu-Fe sulphide melt and 2) Pd-sulphide melt which separated from pri Cu-Fe sulphide melt.

Introduction

The report describes the mineralogy of sample 90-10 445 from the 445-446 m interval of Pd5 level in core 90-10 in the "Platinova Reef" of the Skaergaard intrusion (Andersen et al., 1998; Nielsen et al. 2005). The report is based on concentrates of PGMs produced using a new patented model of Hydroseparator CNT-HS-11 and a polished section of a chip from the core. Mounts with concentrates and the polished section of the gabbro were studied using electron microscopy and electron microprobe analysis (Camscan-4DV, Link AN-10 000). The report gives: (1) grain characteristics, (2) the parageneses and (3) the compositional variations for the identified groups of minerals of the host rock, the base metal sulphides, and precious metal minerals and phases.

The investigation was carried out in 2010.

Sample 90-10 445

Sample 90-10 445 was collected from drill core # 90-10 in the 45-446 m interval. The sample collects the Pd5 level in core 90-10. The core has previously been sampled for other purposes and the represents app. 60% recoverey. The 557g sample collects 1/3 of the diameter of the preserved core. Assays give 2491 ppb Pd, 142 ppb Au, and 129 ppb Pt for this interval.

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003) The heavy mineral HS-concentrates, enriched in precious metal minerals were obtained using a new patented model of the computer controlled Hydroseparator CNT-HS-11 and a newly patented glass separation tube (GST) (Rudshevsky & Rudashevsky, 2006 and 2007). One polished section was prepared from the fragment of the sample (Plate 1).

The remaining core material was crushed to –125 µm. After complete grinding, the sample was wet sieved into the following fraction: (1) <40 µm (227 g), (2) 40-70 µm (100 g), (3) 70-125 µm (126 g), and (4) >125 µm (29 g, not studied).

After wet magnetic separation, the powdered fractions with grain sizes <40 µm, 40-70 µm, 70-125 µm were passed through hydroseparator CNT-HS-11. The studied monolayer polished sections were produced from all grain size fractions of the heavy mineral concentrates (Plate 2).

Results

Rock forming minerals and sulphides

Silicates and FeTi-oxides

The silicates and FeTi-oxides related to sulphides and precious metal phases are: 1) *plagioclase*, $An_{45.8-46.4}$, average $An_{45.9}$ (Table 1, analyses 1- 5); 2) monoclinic ferrous *pyroxene*, Mg# = 0.613-0.632, average 0.620 (Table 1, analyses 6- 9), 3) orthorhombic ferrous *pyroxene*, Mg# = 0.525-0.527, average 0.526 (Table 1, analyses 10-12, average analysis 13) and Fe-Ti oxides including 4) *ilmenite* (Table1, analyses 25- 30), 5) *titaniferous magnetite*, TiO_2 10.6-23.5 wt.%, average 15.6 wt.% (Table 1, analyses 19- 24); monoclinic and orthorhombic pyroxenes form typical exsolution texture (Plate 1, #*3*); serpentine, Mg# = 0.785 (Table 1, analysis 31).

The Fe-Ti-oxides occur as aggregates of 0.1-3 mm, anhedral grains. They fill the space between grains of plagioclase and pyroxenes (Plate 1, #*1, 2, 4-6*). Some fine grains of Fe-Ti oxides (<20 µm) have the form of droplets. They occur as inclusions in pyroxenes, as well as in plagioclase. The gabbro exhibits the characteristic reaction relationships between cumulus and intercumulus phases (see also Holness et al., 2011), a reaction believed caused by the occurrence of insterstitial immiscible Fe-rich silicate melt., whos presence accounts for the dtroplets of FeTi-oxides in pyroxene and plagioclase in accordance with Jakobsen et al. (2011).

Three grains of zircon - one of them with thorionite inclusion - as well as one uraninite particle were identified in the heavy mineral concentrates (Plate 3). The occurrence of these phases in the sample opens for the possibility for geochronologicaland isotopic investigations.

The host rock of sample 90-1 445 is a fairly “dry” rock. H_2O-bearing minerals are locally represented. The reaction rims of olivine are on some parts replaced by serpentine and magnetite aggregates (Plate 1, #*1, 2, 8*). In addition, H_2O-bearing minerals occur in very small amounts in intergrowths with Cu-Fe-sulphides and PGMs.

Sulphides

Aggregates of fine bornite grains (<20 µm) were occur in the olivine rims at the boundaries between grains of Fe-Ti oxide and pyroxene (Plate 1, #*4, 5, 8*), as well as in aggregates of plagioclase and pyroxenes (Plate 1, #*7*). The grains of bornite can be clear droplets (Plate 1, #*5, 6*) or anhedral and irregular (Plate 1, #*4, 5, 8*).

The nonmagnetic heavy mneral HS-concentrates are ilmenite-rich products (> 90 %). They are enriched by grains of base metal sulphides and precious metal minerals (Plate 2).

The sulphide grains observed between the ilmenite grains of the monolayer samples (Plate 2) are dominanted by bornite or bornite and chalcopyrite with minor chalcopyrite. Few grains are composed of bornite and chalcosine, digenite, pentlandite, and pyrrhotite (see Plate 4. The relative proportions between the base metal sulphides in sample 90-10 445 were estimated from a random selection of 162 grains in the heavy mineral HS-concentrates (<70 μm fraction):

Minerals in grain	Number of grains	%
Bornite	131	80.9
Bornite+halcopyrite	12	7.4
Chalcopyrite	8	4.9
Pentlandite	4	2.5
Pyrrhotite	1	0,6
Pyrrhotite+chalcopyrite	1	06
Bornite+chalcosine	2	1.2
chalcosine	2	1.2
digenite	1	0.6
Total	162	100

The sulphides include: (A) microglobules of bornite (Plate 4, # *1, 2*), bornite and chalcopyrite (Plate 4, #*10, 11*) and chalcopyrite (Plate 1, #*17*) and (B) irregular-shaped grains (see Plate 4). Chalcopyrite occurs in classic exsolution textures in bornite hosts (Plate 4)

The compositions of bornite (Table 2, analyses 1-17), chalcopyrite (Table 2, analyses 18-23), chalcosine (Table 2, analyses 24, 25) and digenite (Table 2, analysis 26) are all near-stoikiometric. The average composition of pentlandite (Table 2, analysis 30) corresponds to the formula $(Ni_{4.58}Fe_{4.38}Co_{0.03})_{6.99}S_{8.01}$. Pyrrhotite compositions (Plate 2, analyses 31, 32) are close to the formula $(Fe,Ni)_7S_8$ and characteristic for the monoclinic pyrrhotite modification.

PGMs: recovery, grain size and relations to host rock

Recovery

Despite of the high concentration of precious metals in the sample (>2 ppm), studied polished section of the gabbro is quite poor in PGMs. One grain of bornite, only, with 3 very small (1-3 μm) inclusions of Pd arsenide (guanglinite?) was identified (Plate 1, #*8*).

The heavy mineral HS-concentrates yielded 23 PGM-bearing particles. At least 8 platinum group minerals are documented in sample 90-10 445. They include:

1. *vasilite* $(Pd,Cu,Fe)_{16}S_7$ - in 8 particles,
2. *guanglinite* $(Pd,Pt)_3(As,Sn)$ – in 8 particles;
3. *vysotskite* (Pd,Ni,Cu,Fe)S – in 7 particles;
4. *atokite* Pd_3Sn- in 2 particles;
5. *unnamed* $Pd_{11}As_2Sn_2$– in one particle;
6. *skaergaardite* (Pd,Au,Pt)(Cu,Fe,Zn) – in one particle;
7. *(Pt,Fe,Cu) alloy* – in one particle;
8. *zvyagintsevite* $Pd_3(Pb,Sn)$ – in one particle.

The area proportions are calculated from the area of grains of these minerals (Tables 3, 4 and Fig. 1).

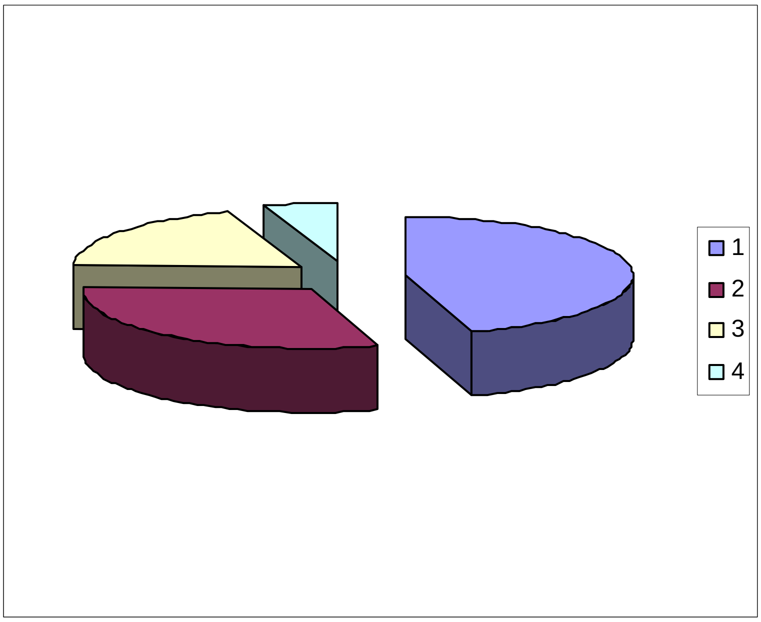

Fig.1. PGMs in the heavy mineral HS-concentrates of the sample 90-10, 445 (see Table 3): 1) vasilite (45.4 %); 2) guanglinite (30.3 %); 3) vysotskite (!9.1 %); 4) atokite, unnamed $Pd_{11}As_2Sn_2$, skaergaardie, (Pt,Fe) alloy and zvyagintsevite (5.2 %)

Grain size

Grain size was estimates as the effective diameter of the grains (ECD) using the “imageJ” ® software. It varies from 1 to 29 µm with an average of 14 µm (Tables 3, 4).

The scanning electron images of the grains suggests that the majority of PGM grains are preserved and have kept their primary shape and size (Plates 5-8). The grains do not seeem to have not been broken during the production of the concentrates. The largest proportion of grains of precious metal minerals are concentrated in the <40 µm fraction.

Petrographic observations

The almost perfect separation of accessory minerals was achieved by gentle crushing and disintegration of the studied sample. The method of disintegration allows preservation of the grains grains and recovery of the most important information required for reconstructionn of the genesis of minerals. The concentrates provide full information on the primary shapes and sizes of accessory phases, their paragenesises, and their associations and relationship with the host rock.

In the HS-concentrates of the sample 90-10 445 the PGM grains (n = 23) occur in the following mineral associations (Fig. 2; Table 5):

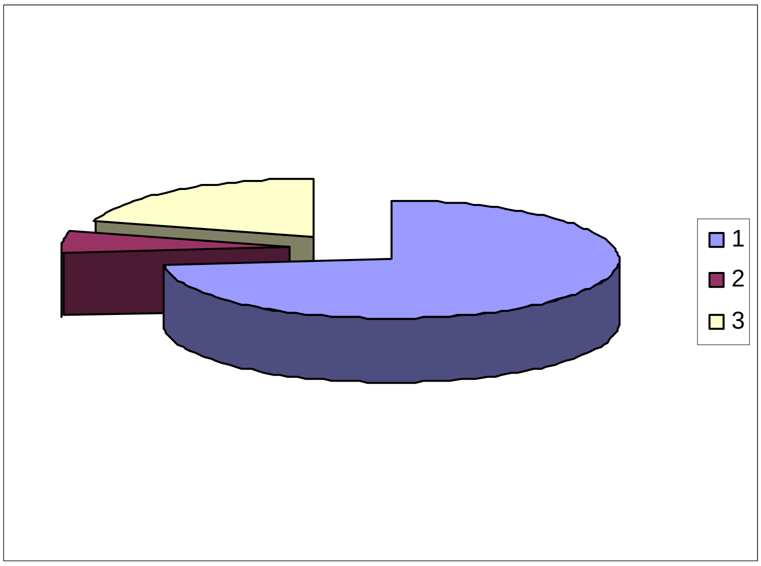

Fig. 2. PGE-minerals grouped by associations, sample 90-10 445: 1) bms and bms-L associations (73.5 %); 2) sag association (5.9 %); 3) Lp association (20,6 %).

Based on SEIs, PGMs in the heavy concentrates are divided in different groups:

1. vasilite-bearing particles (Plate 5);

2. guanglinite-bearing particles (Plate 6);
3. vysotskite-bearing particles (Plate 7);
4. particles with other PGMs (atokite, unnamed $Pd_{11}As_2Sn_2$, skaergaardite, Pt-Fe alloy, zvyagintsevite) - (Plate 8).

Description and chemistry of PGMs

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

Description
Vasilite is one of the main Pd minerals inthe HS-concentrates of the sample 90-10 445 (45.4 area %). It is always found in intergrowths with Cu-Fe sulphides (bornite and chalcopyrite) - (Plate 5; Plate 8, #*3,4*). Some vasilite grains are also associated to the PGMs guanglinite and atokite (Plate 8, #*3, 4*).

Vasilite-bearing sulphide grains can be either droplets (Plate 5, #*1, 3, 4, 6* ; Plate 8, #*3*) or irregular-shaped aggregates (Plate 5, #*2, 5, 7*). Often, vasilite grains are localized at the margin of sulphide globules (Plate 5, #*1-4*).

Vasilite grains occur as:

1. isometric droplets (Plate 5, #*1-4*; Plate 8, #*3, 4*);
2. euhedral to subhedral crystals (Plate 5, #*5, 7*).

The size of the vasilite grains varies from 9 to 26 µm with an average of 18 µm (Table 3).

Mineral chemistry
The chemical composition of vasilite is constrained by 5 analyses in 5 particles (Table 6). Thje average composition of vasilite (Table 6, analysis 6) is (wt. %): Pd 72.4, Cu 14.0, Fe 0.4, S 12.7, Total 99.5. The composition corresponds to the formula:

$$(Pd_{12.01}Cu_{3.90}Fe_{0.12})_{16.03}S_{6.98}.$$

Guanglinite $(Pd,Pt)_3(As,Sn)$

Description
Together with vasilite, guanglinite is one of the main Pd minerals in the HS-concentrates of the sample 90-10 445 (30.3 area %). Mostly, guanglinite occurs in the concentrates in intergrowths with the Cu-Fe sulphides bornite and chalcopyrite (Plate 6). Guanglinite is also observed in clinopyroxene – Plate 6, #*2*). The concentrates also contain completly

liberated PGM particles, where guanglinite is associated to (Pt,Fe) alloy (Plate 8, #*1*) or to atokite, zvyagintsevite and the unnamed mineral $Pd_{11}As_2Sn_2$ mineral (Plate 8, #*2*).

In general guanglinite-bearing sulphide grains are anhedral and irregular in shape (see Plate 6), The guanglinite grains may be irregular (see Plate 6; Plate 8, #*1*), but occasional euhedral crystals of guanglinite can be observed (Plate 8, #*2*).

The grain size of guanglinite varies between 1 and 26.5 µm with an average of 12 µm (Table 3).

Mineral chemistry

The composition of guanglinite is constrained by 4 analyses in 4 particles (Table 7). The average composition of guanglinite (Table 7, analysis 5) is the wt. %): Pd 78.9, Pt 1.9, As 18.6, Sn 1.3, Total 99.5. The composition corresponds to the formula:

$$(Pd_{2.98}Pt_{0.03})_{3.01}(As_{0.95}Sn_{0.05})_{1.00}.$$

Typical substitutions in guanglinite are: Pt up to 3.5 % (Table 7, analysis 2) and Sn up to 5.2 % (Table 7, analysis 3).

Vysotskite (Pd,Ni,Cu,Fe)S

Description

Vysotskite is with 19.1 area% the third main Pd mineral in the HS-concentrates of the sample 90-10 445. It is always found in intergrowths with bornite and chalcopyrite (Plate 7). The vysotskite-bearing sulphide grains as well as the vysotskite grains are irregular aggregates (see Plate 7). Usually vysotskite grains are localized at the margin of their sulphide host.

The grain size of vysotskite varies from 3 to 27 µm with an average of 11 µm (Table 3).

Mineral chemistry

The composition of vysotskite is constrained by 5 analyses in 5 particles (Table 8). The average composition of vysotskite (Table 8, analysis 6) is (wt. %): Pd 67.4, Ni 1.7, Cu 1.0, Fe 0.7, S 23.5, Total 99.3. The composition corresponds to the formula:

$$(Pd_{0.91}Ni_{0.04}Cu_{0.03}Fe_{0.o2})_{1.00}S_{1.00}.$$

Rare PGMs

Five other PGMs, were found in the heavy mineral HS concentrate. They constitute app. 5 area% of the paragenesis and include: 1) atokite, 2) unnamed mineral phase $Pd_{11}As_2Sn_2$ in composition, 3) skaergaardite, 4) Pt-Fe alloy, and 5) zvyagintsevite (see Table 3).

Atokite Pd_3Sn

Atokite Pd_3Sn (2.6 area% of all PGMs) occurs in two PGM-bearing particles: 1) in association with other PGMs (guanglinite, unnamed $Pd_{11}As_2Sn_2$ and zvyagintsevite (Plate 8, #*2*); and 2) in a bornite and chalcopyrite host together with the PGMs vasilite and guanglinite (Plate 8, #*3, 4*). The atokite grains are anhedral and irregular, and the size of the grains varies between 4.4 and 12.2 μm, with an average of 8 μm.

The composition of atokite is stoikiometric and the formula is $Pd_{3.01}Sn_{0.99}$ (Table 9, analysis 1).

Unnamed $Pd_{11}As_2Sn_2$ (Sn isomerteite?)

The unnnamed mineral or phase $Pd_{11}As_2Sn_2$ (11.3 μm in size; 1.9 area % of all PGMs) occurs in one liberated PGM particle together with guanglinite, atokite and zvyagintsevite (Plate 8, #*2*). The composition of this mineral (Table 9, analysis 4) correspond to formula $Pd_{11}As_2Sn_2$. and is probably a Sn-analog of isomertieite $Pd_{11}As_2Sb_2$.

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

One grain, only, of skaergaardite (5.6 μm in size; 0.5 area % of all PGMs) was found as an inclusion in the margin of a bornite globule (Plate 8, #*5*; Table 9; analysis 2).

(Pt,Fe) alloy

In the heavy mineral concentrate one grain of (Pt,Fe) alloy (3.4 μm; 0.2 area % from all PGMs) was found as inclusion in guanglinite (Plate 8, #*1*; Table 9, analysis 3).

Zvyagintsevite(?) Pd_3(Pb,Sn)

One grain, only, of zvyagintsevite (?) Pd_3(Pb,Sn) (~1 μm in size; analysed by X-ray spectra on the microprobe; <0.1 area% from all PGMs) was found as inclusion in atokite together with guanglinite and unnamed $Pd_{11}As_2Sn_2$ (Plate 8, #*2*).

Discussion

The sulphide-PGM paragenesis

Bornite and chalcopyrite are the absolutely dominant suphides in the Pd5 level of the Skaergaard mineralization (>93 %). The occur as inclusions in cumulus two-pyroxenes aggregates (Plate 1, # *6*), as well as in olivine reaction rims between of Fe-Ti aggregates and pyroxenes (Plate 1, # *4, 5, 8*) and in inter cumulus plagioclase (Plate 1, # *7*).

Grains of bornite and chalcopyrite, form characteristic droplet-like microglobules (see Plate 1, #*5, 6*; Plate 4, # *1, 2 , 10, 11, 17*) as well as with irregular-shaped aggregates. The characteristic exsolution textures of the bornite-chlacopyrite grains (Plate 4, #*10-15*) confirm the primary high temperature nature of these sulphide grains and globules..

PGMs of the studied sample are closely related to the Cu-Fe sulphides. Apart from two liberated PGM particles (Plate 8, #*1, 2*), all PGMs are associated with bornite and chalcopyrite (see Fig.2; Plates 5-8). The PGMs are in sample 90-10 445 represented mainly by the Pd-sulphides vasilite and vysotskite and the Pd-arsenides (guanglinite) - (see Table 3, Fig. 1).

Note should be taken of the droplets of vasilite (Plate 5, # *1-4*; Plate 8, #*3, 4*) and of the ocuurrence of the Pd-sulphides vasilite and vysotskite at the margins of the Cu-Fe sulphide globules (see Plates 5, 7, 8, #*3, 4*).

Order of crystallization

The presence of Cu-Fe sulphide droplets in cumulus as well as inter cumulus of matrix gabbro suggests that sulphide melt was present from the start of the crystallization of the host.

All the observations suggests the Cu-Fe sulphides and PGMs are contemporaneous. All the observations of the inter-grain relations suggest that all PGMs are part of a single CuFe sulphide-PGM paragenesis.

The characteristic droplet shape of both host Cu-Fe sulphides and PGMs suggests that the host droplets as well as the enclosed PGM droplets were immiscible melts: 1) a Cu-Fe sulphide melt and 2) a sulphide melt enriched by Pd, Cu, Pt and Au which was separated from the primary Cu-Fe melt. The occurrence of such melts is documented by Karup Møller and Makovicky (1999) and Karup-Møller et al. (2008).

Summary

Twenty-three PGM-bearing particles in the heavy mineral HS-concentrates of sample 90-10, 445 were obtained from 0.56 kg of sampleusing HS-technology. The grains were studied in detail using microprobe analysis. Main platinum group minerals (PGMS) are: vasilite $(Pd,Cu,Fe)_{16}S_7$ – 45.4 area. %, guanglinite $(Pd,Pt)_3(As,Sn)$ – 30.3 area % and vysotskite (Pd,Ni,Cu,Fe)S -19.1 area %. In addition, 5 other PGMs were identified (~ 5 area. % all together): atokite Pd_3Sn – 2.6 area %, unnamed $Pd_{11}As_2Sn_2$ – 1.9 area %, skaergaardite (Pd,Au,Pt)(Cu,Fe,Zn) – 0.5 area %, (Pt,Fe,Cu) alloy – 0.2 area % and zvyagintsevite $Pd_3(Pb,Sn)$ – <0.1 area %). The grain size of the PGMs (ECD) varies between 1 and 29 μm with an average of 14 μm.

The Pd-sulphides vasilite and vysotskite and the Pd-arsenides guanglinite totally dominate the PGM paragenesis. Pt is found as an inclusion of (Pt,Fe) alloy in guanglinite and skaergaardite. Native Au minerals were not found, detacted Au is substituded into skaergaardite.

Bornite and chalcopyrite totally dominate the sulphide paragenesis (>93 %). The presence of Cu-Fe sulphide droplets in cumulus as well as intercumulus minerals indicates that the sulphide melt was present during all the crystallization of the host. The characteristic exsolution textures in bornite-chalcopyrite globules support the interpretation of the globules as liquidus high T product of saturation in the basltic magma. The formation of the Cu-Fe sulphides and PGMs is contemporaneous. All PGMs and sulphides are part of a single originnally high-T paragenesis.

Several zircon grains were found in the heavy mineral HS-concentrates. They can be used for geochronological and isotopic investigations of the ore horizon.

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Appendix

List of abbreviations

Rock-forming minerals
pl – plagioclase
cpx – monoclinic pyroxene
opx – orthorhombic pyroxene
ol - olivine
mt - magnetite
ilm - ilmenite
timt – titaniferous magnetite
chl – chlorite
q – quartz
pyr (exs) – exsolution texture of monoclinic and orthorhombic pyroxenes
srp – serpentine
zrn – zircon
ThO_2 – thorionite
UO_2 - uraninite

Sulphides
bn - bornite
cp – chalcopyrite
pn – pentlandite
po –pyrrhotite
chal – chalcosihe
dgn – digenite

Precious metal minerals
gng – guanglinite
vsl - vasilite
vys – vysotskite
at – atokite
sk - skaergaardite
zv - zvyagintsevite
(Pt,Fe) – alloys of Pt and Fe
$Pd_{11}As_2Sn_2$ – unnamed mineral phase

TABLES

Table 1. Compositions of host rock silicates and oxides, sample 90-10 445

	Plagioclase					Monoclinic pyroxene				Orthorhombic pyroxene				Olivine				
Analysis (wt%)	1	2	3	4	5 avr.	6	7	8	9 avr.	10	11	12	13 avr	14	15	16	17	18 avr.
SiO_2	55.9	56.1	56.3	56.1	56.1	50.9	51.8	50.8	51.2	51.1	51.8	51.4	51.4	35.7	35.7	33.9	35.0	35.1
TiO_2	-	-	-	-	-	0.9	0.5	0.8	0.7	0.3	0.3	0.4	0.3	-	-	-	-	-
Al_2O_3	27.5	27.2	27.3	27.5	27.4	1.4	1.1	1.4	1.3	0.8	-	-	0.3	-	-	-	-	-
V_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe_2O_3	0.6	0.5	0.5	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-
FeO	-	-	-	-	-	14.7	14.7	14.5	14.6	26.6	27.2	27.1	27.0	36.7	35.5	42.9	38.4	38.4
MnO	-	-	-	-	-	0.3		0.4	0.2	0.7	0.7	0.8	0.7	0.4	0.5	0.4	0.5	0.5
MgO	-	-	-	-	-	12.9	14.0	12.9	13.3	16.5	17.2	16.7	16.8	26.5	27.9	21.9	25.9	25.6
CaO	9.3	9.1	9.3	9.3	9.3	18.5	18.0	18.7	18.4	3.4	2.9	3.2	3.2	-	-	-	-	-
Na_2O	6.1	5.9	6.2	5.9	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-
K_2O	0.5	0.5	0.4	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	99.9	99.3	100.0	99.8	99.8	99.6	100.1	99.5	99.7	99.4	100.1	99.5	99.7	99.3	99.6	99.1	99.8	99.6
Cations									F.c.									
Si	2.52	2.54	2.54	2.53	2.53	1.94	1.96	1.94	1.95	1.98	1.99	1.99	1.99	1.01	1.00	0.99	0.99	1.00
Ti	-	-	-	-	-	0.03	0.01	0.02	0.02	0.01	0.01	0.01	0.01	-	-	-	-	-
Al	1.46	1.45	1.45	1.46	1.45	0.06	0.05	0.07	0.06	0.04	-	-	0.01	-	-	-	-	-
V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe3+	0.02	0.02	0.02	0.02	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe2+	-	-	-	-	-	0.47	0.46	0.46	0.46	0.86	0.88	0.88	0.87	0.87	0.83	1.05	0.91	0.92
Mn	-	-	-	-	-	0.01		0.01	0.01	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01
Mg	-	-	-	-	-	0.74	0.79	0.73	0.75	0.95	0.98	0.96	0.96	1.11	1.16	0.95	1.09	1.08
Ca	0.45	0.44	0.45	0.45	0.45	0.76	0.73	0.76	0.75	0.14	0.12	0.13	0.13	-	-	-	-	-
Na	0.53	0.52	0.54	0.52	0.53	-	-	-	-	-	-	-	-	-	-	-	-	-
K	0.03	0.03	0.02	0.03	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
O-basis	8	8	8	8	8	6	6	6	6	6	6	6	6	4	4	4	4	4
Cation basis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
An%	0.46	0.46	0.45	0.46	0.46	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg#	-	-	-	-	-	0.61	0.63	0.61	0.62	0.52	0.53	0.52	0.52	0.56	0.58	0.48	0.55	0.54

Table 1 continued

	Titaniferous magnetite						Ilmenite						Serpentine
Analysis	19	20	21	22	23	24 avr.	25	26	27	28	29	30 avr.	31
(wt%)													
SiO_2	-	-	-	-	-	-	-	-	-	-	-	-	40.3
TiO_2	16.1	14.1	10.6	13.5	23.5	15.6	49.0	52.6	52.3	52.4	52.3	51.7	-
Al_2O_3	3.6	3.2	1.3	2.8	3.5	2.9	-	-	-	-	-	-	-
V_2O_3	1.6	1.5	0.8	1.6	1.1	1.5	0.5	-	-	-	-	-	-
Fe_2O_3	31.7	37.1	46.8	38.8	18.1	34.5	8.1	2.0	1.6	1.5	1.9	3.0	-
FeO	46.5	42.4	39.2	42.6	53.4	44.8	40.3	43.1	43.2	43.2	42.6	42.5	17.3
MnO	-	-	-	-	-	-	0.4	0.4	0.4	0.9	0.6	0.5	0.4
MgO	-	1.5	1.3	1.1	-	0.8	1.9	2.1	1.9	1.7	2.2	2.0	30.3
CaO	-	-	-	-	-	-	-	-	-	-	-	-	-
Na_2O	-	-	-	-	-	-	-	-	-	-	-	-	-
K_2O	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	99.5	99.8	100.0	100.4	99.6	100.1	100.2	100.2	99.4	99.7	99.6	99.7	88.3
Cations													
Si	-	-	-	-	-	-	-	-	-	-	-	-	2.01
Ti	0.45	0.39	0.30	0.38	0.65	0.43	0.92	0.98	0.98	0.99	0.98	0.97	-
Al	0.16	0.14	0.06	0.12	0.15	0.13	-	-	-	-	-	-	-
V	0.05	0.04	0.02	0.05	0.03	0.04	0.01	-	-	-	-	-	-
Fe3+	0.89	1.03	1.32	1.08	0.51	0.97	0.15	0.04	0.03	0.03	0.04	0.06	-
Fe2+	1.45	1.31	1.23	1.32	1.65	1.39	0.84	0.89	0.90	0.90	0.89	0.88	0.72
Mn	-	-	-	-	-	-	0.01	0.01	0.01	0.02	0.01	0.01	0.02
Mg	-	0.08	0.07	0.06	-	0.04	0.07	0.08	0.07	0.06	0.08	0.07	2.25
Ca	-	-	-	-	-	-	-	-	-	-	-	-	-
Na	-	-	-	-	-	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-	-	-	-	-	-
O-basis	-	-	-	-	-	-	-	-	-	-	-	-	7
Cation basis	3	3	3	3	3	3	2	2	2	2	2	2	-

Table 2. Composition of base metal sulphides in sample 90-10 445

	Bornite																
Point/grain	40-I,#1b	40-I,#1c	40-I,#2a	40-I,#3	40-I,#4a	40-I,#5	40-I,#5a	40-I,#5c	40-I,#5l	40-I,#6	40-I,#6b	40-2,#4	70,#1	125,#1	125,#2	125,#1	Average
Association	bn	bn	bn	vsl+bn	bn	vsl+bn	bn	cp+bn	bn+chal	vys+bn	bn	vys+bn	vsl+bn	vys+bn	gng+bn	vsl+bn +cp	bn
Analysis #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
wt%																	
Fe	11.2	11.2	11.1	11.3	11.5	11.2	11.5	11.2	11.3	11.1	11.5	11.2	11.6	11.2	11.2	11.4	11.1
Co	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	62.7	63.3	63.0	63.5	62.6	63.0	63.2	62.7	62.6	63.0	62.3	62.8	62.3	62.8	62.9	62.7	62.8
S	25.4	25.7	25.6	25.4	25.6	26.0	25.7	25.2	25.5	25.3	25.8	25.8	25.5	25.4	25.4	25.5	25.6
sum	99.3	100.2	99.7	99.7	99.7	100.2	100.4	99.1	99.4	99.4	99.1	99.8	99.4	99.4	99.5	99.6	99.7
Proportions																	
Fe	1.02	1.01	1.00	1.01	1.03	1.00	1.03	1.01	1.02	1.01	1.04	1.01	1.05	1.01	1.01	1.03	1.02
Co	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	4.99	4.99	4.99	5.01	4.96	4.95	4.97	5.00	4.97	5.00	4.96	4.96	4.94	4.99	4.99	4.96	4.98
S	4.00	4.01	4.01	3.98	4.01	4.05	4.00	3.99	4.01	3.99	4.00	4.03	4.01	4.00	4.00	4.01	4.01
sum	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

Abbreviations: vsl: vasilite; vys: vysotskite; gng: guanglinite; bn: bornite; cp: chlcopyrite; chal:chalcosine; po: pyrrhotite; dgn: digenite; pn: pentlandite.

Table 2 continued

	Chalcopyrite						Chalcosine		Digenite	Pentlandite				Pyrrhotite	
Point/grain	40-I,#5c	40-I,#6a	40-I,#13	40-2,#4d	125,#1	Average	40-I,#5l	40-2,#4k	40-2,#4g	40-2,#4c	40-2,#4h	40-2,#4i	Average	40-2,#4b	40-2,#4d
Association	cp+bn	cp	vys+cp +chl	cp+po	vsl+bn +cp	cp	bn+chal	chal	dgn	pn	pn	pn	pn	po	cp+po
Analysis #	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
wt%															
Fe	29.9	30.2	30.3	29.9	29.7	30.0	1.0	0.9	1.7	32.4	32.0	30.6	31.7	58.6	59.9
Co	-	-	-	-	-	-	-	-	-	-	0.6	-	0.2	-	-
Ni	-	-	-	-	-	-	-	-	-	34.6	33.4	36.2	34.7	0.6	-
Cu	35.7	34.6	34.3	34.6	35.1	34.9	77.8	77.6	76.4	-	-	-	-	-	-
S	34.9	34.6	34.3	34.8	35.2	34.8	20.3	20.5	21.9	33.2	33.2	33.2	33.2	39.9	39.5
sum	100.5	99.4	99.1	99.3	100.0	99.7	99.1	99.0	100.0	100.2	99.2	100.0	99.8	99.1	99.4
Proportions															
Fe	0.98	1.00	1.01	0.99	0.97	0.99	0.03	0.03	0.22	4.47	4.45	4.23	4.38	6.83	6.98
Co	-	-	-	-	-	-	-	-	-	-	0.08	-	0.03	-	-
Ni	-	-	-	-	-	-	-	-	-	4.54	4.42	4.77	4.58	0.08	-
Cu	1.03	1.00	1.00	1.01	1.01	1.01	1.96	1.95	8.79	-	-	-	-	-	-
S	1.99	2.00	1.99	2.01	2.01	2.00	1.01	1.02	4.99	7.98	8.05	8.00	8.01	8.10	8.02
sum	4	4	4	4	4	4	3	3	14	17	17	17	17	15	15

Abbreviations: vsl: vasilite; vys: vysotskite; gng: guanglinite; bn: bornite; cp: chlcopyrite; chal:chalcosine; po: pyrrhotite; dgn: digenite; pn: pentlandite.

Table 3. Precious metal minerals in the heavy mineral HS-concentrates, sample 90-10 445

Mineral	General formula	Number of grains	n%	Area%	Grain size, µm		
					min	average	max
Vasilite	$(Pd,Cu,Fe)_{16}S_7$	8	27.6	45.4	9.2	18.3	26.1
Guanglinite	$(Pd,Pt)_3(As,Sn)$	8	27.6	30.3	1.3	12.2	26.5
Vysotskite	(Pd,Ni,Cu,Fe)S	7	24.1	19.1	3.0	10.6	27.2
Atokite	Pd_3Sn	3	6.9	2.6	4.4	8.3	12.2
Unnamed	$Pd_{11}As_2Sn_2$	1	3.4	1.9		11.3	
Skaergaardite	(Pd,Au,Pt)(Cu,Fe,Zn)	1	3.4	0.5		5.6	
Alloy	(Pt,Fe,Cu)	1	3.4	0.2		3.4	
Zvyagintsevite	$Pd_3(Pb,Sn)$	1	3.4	<0,1		1.1	
	Total	30	100	100			

Table 4. Grain sizes of platinum group minerals from HS-concentrates in the sample 90-10 445

N	Grain#	Association	Type	Mineral	Area, μm^2	ECD, µm
1	40,#1	vys-bn-cp	bms	vys	581	27.2
2	40,#2	gng-cp	bms-L	gng	552	26.5
3	40,#3	vsl-bn	bms	vsl	189	15.5
4	40,#4	gng-cp-cpx	sag	gng	139	13.3
5	40,#5	vsl-bn	bms-L	vsl	462	24.3
6	40,#6	vys-bn	bms	vys	20	5.0
7	40,#7	gng-nb-cp	bms	gng	5	2.5
8	40,#8	gng-bn-chl	sag	gng	1.4	1.3
9	40,#9	vys-bn	bms	vys	30	6.2
10	40,#10	vsl-bn-cp	bms	vsl	94	10.9
11	40,#11	vys-bn	bms	vys	11	3.7
12	40,#12	vys-bn-cp	bms	vys	7	3.0
13	40,#13	vus-cp-chl	sag	vys	164	14.5
14	40-2,#1	gng-at-Pd11As2Sn2-zv	Lp	gng	643	28.6
15	40-2,#1	gng-at-Pd11As2Sn2-zv	Lp	gng	425	23.3
16	40-2,#1	gng-at-Pd11As2Sn2-zv	Lp	at	117	12.2
17	40-2,#1	gng-at-Pd11As2Sn2-zv	Lp	Pd11As2Sn2	100	11.3
18	40-2,#1	gng-at-Pd11As2Sn2-zv	Lp	zv	1	1.1
19	40-2,#2	vsl-bn	bms-L	vsl	505	25.4
20	40-2,#3	gng-(Pt,Fe)	Lp	Total	416	23.0
21	40-2,#3	gng-(Pt,Fe)	Lp	gng	407	22.8
22	40-2,#3	gng-(Pt,Fe)	Lp	(Pt,Fe)	9	3.4
23	40-2,#4	vsl-bn	bms	vsl	179	15.1
24	40-2,#5	sk-bn	bms	sk	25	5.6
25	70,#1	vsl-bn	bms	vsl	308	19.8
26	70,#2	vsl-gng-at-bn	bms	Total	580	27.2
27	70,#2	vsl-gng-at-bn	bms	vsl	534	26.1
28	70,#2	vsl-gng-at-bn	bms	gng	31	6.3
29	70,#2	vsl-gng-at-bn	bms	at	15	4.4
30	125,#1	vys-cp	bms	vys	170	14.7
31	125,#2	gng-bn	bms	gng	2	1.6
32	125,#3	vsl-bn-cp	bms	vsl	67	9.2

Table 5. Platinum Group mineral associations in sample 90-10 445

Association	PGMs, Number of grains	PGMs, area%
LP	2	20.6
bms	15	44,0
bms-L	3	29,5
sag	3	5,9
Total	23	100

LP: two or more PGMs-bearing completely liberated (free) particles;
bms: intergrowths with base metal sulphides (bornite, chalcopyrite);
bms-L: liberated particles with <10 % attached base metal sulphides;
sag: sulphide and gangue attached to PGM

Table 6. Composition of vasilite, sample 90-10 445

grain/point Association	40-I,#3 vsl+bn	40-I,#5 vsl+bn	70,#1 vsl+bn	70,#2 vsl+gng +at+bn +cp	125,#3 vsl+bn +cp	Average
Analysis #	**1**	**2**	**3**	**4**	**5**	**6**
wt%						
Fe	0.6	-	0.4	-	0.9	0.4
Cu	14.3	13.9	14.0	13.6	14.3	14.0
S	12.7	12.7	12.7	12.6	12.7	12.7
Pd	71.8	73.1	72.5	73.3	71.2	72.4
sum	99.4	99.7	99.6	99.5	99.1	99.5
Proportion						
Fe	0.18	-	0.12	-	0.29	0.12
Cu	3.97	3.86	3.90	3.80	3.97	3.90
S	6.98	7.01	6.96	6.97	6.98	6.98
Pd	11.88	12.13	12.02	12.23	11.77	12.01
sum	23	23	23	23	23	23

Abbreviations: vsl: vasilite; gng: guanglinite; at: atokite; cp: chalcopyrite; ;bn: bornite

Table 7 . Composition of guanglinite, sample 90-10 445

grain/point Association	40-I,#2 gng+cp	40-I,#4 gng+cp +cpx	40-2,#1 gng+at +un+zv	40-2,#3 gng+ (Pt,Fe)	Average
Analysis #	**1**	**2**	**3**	**4**	**5**
wt%					
Pt	-	3.5	-	1.9	1.3
Pd	81.5	77.2	79.0	78.9	79.2
As	18.8	18.3	15.0	18.6	17.7
Sn	-	-	5.2	-	1.3
Total	100.3	99.0	99.2	99.4	99.5
Proportion					
Pt	-	0.07	-	0.04	0.03
Pd	3.01	2.94	3.01	2.97	2.98
As	0.99	0.99	0.81	0.99	0.95
Sn	-	-	0.18	-	0.05
Total	4	4	4	4	4

Abbreviations gng: guanglinite; at:atokite ; zv:zvyagintsevite ; un: unknown phase; (Pt,Fe): alloy; cp: chalcopyrite; bn: bornite.

Table 8. Composition of vysotskite, sample 90-10 445

grain/point	40-I,#1	40-I,#6	40-I,#13	40-2,#4	125,#1	Average
Association	vys+bn +cp	vys+bn	vys+cp +chl	vys+bn	vys+bn	
Analysis (wt%)	**1**	**2**	**3**	**4**	**5**	**6**
Fe	0.4	1.1	1.1	0.5	0.5	0.7
Ni	0.5	2.0	-	-	6.0	1.7
Cu	-	1.0	1.8	1.0	1.1	1.0
S	23.0	23.6	23.7	23.4	24.0	23.5
Pd	75.4	71.8	73.2	74.2	67.4	72.4
sum	99.3	99.5	99.8	99.1	99.0	99.3
Proportions						
Fe	0.01	0.03	0.03	0.01	0.01	0.02
Ni	0.01	0.05	-	-	0.14	0.04
Cu	-	0.02	0.04	0.02	0.02	0.03
S	1.00	1.00	1.00	1.01	0.99	1.00
Pd	0.98	0.91	0.93	0.96	0.84	0.91
sum	2.00	2.01	2.00	2.00	2.00	2.00

Table 9 . Composition of atokite, skaergaardite, (Pt,Fe) alloy and unnamed $Pd_{11}As_2Sn_2$, sample 90-10 445

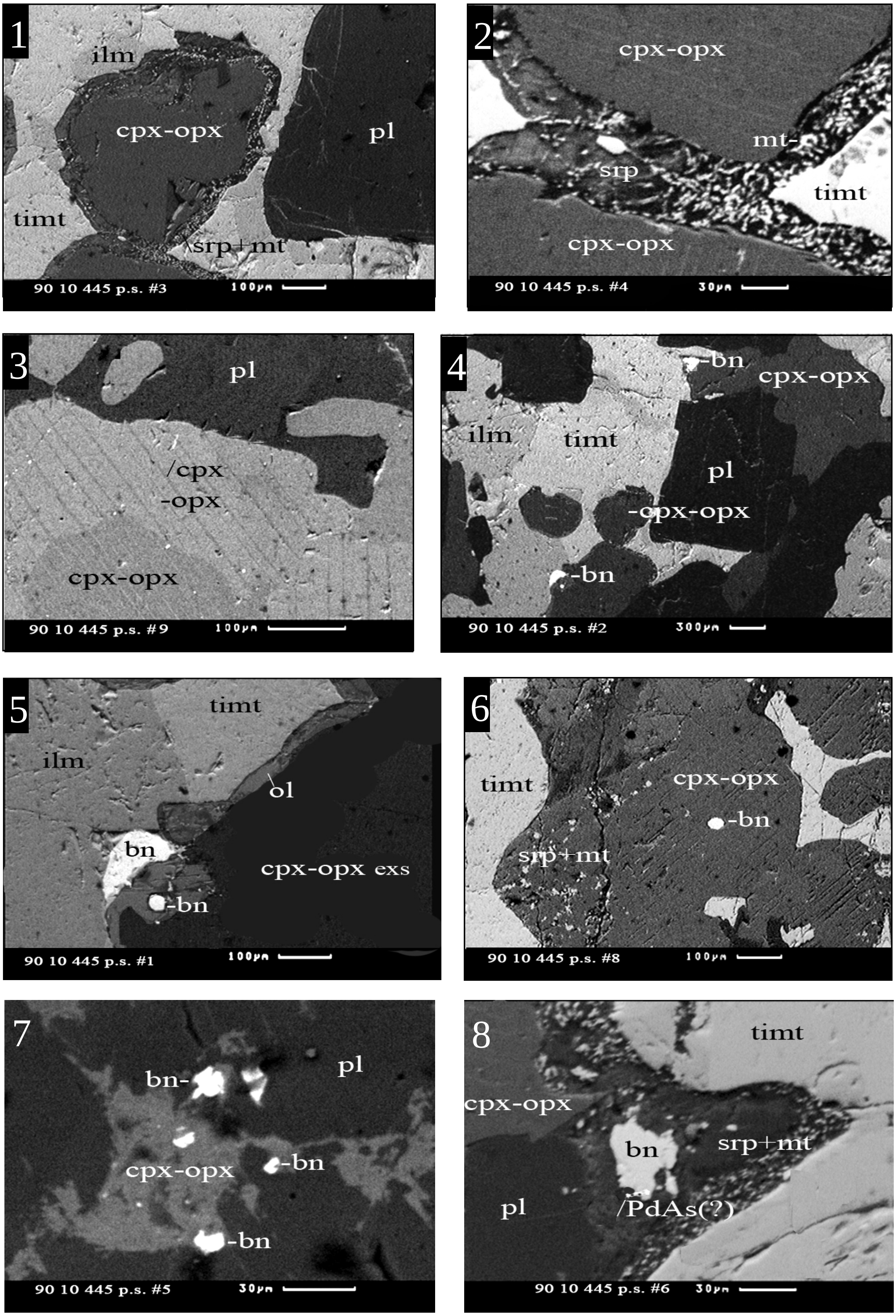
	Atokite	Skaergaardite	(Pt,Fe) alloy	Unnamed $Pd_{11}As_2Sn_2$
grain/point	40-2,#1	40-2,#5	40-2,#3	40-2,#1
Association	gng+at +un+zv	sk+bn	gng+ (Pt,Fe)	gng+at +un+zv
Analysis (wt%)	**1**	**2**	**3**	**4**
Fe	-	3.1	10.3	-
Zn	-	4.7	-	-
Cu	-	29.1	1.0	-
Pt	-	2.7	87.7	-
Pd	72.9	57.5	-	75.30
Au	-	2.5	-	-
As	-	-	-	9.5
Sn	26.7	-	-	14.6
sum	99.6	99.6	99.0	99
Proportions				
Fe	-	0.10	0.28	-
Zn	-	0.12	-	-
Cu	-	0.79	0.02	-
Pt	-	0.02	0.69	-
Pd	3.01	0.94	-	11.09
Au	-	0.02	-	-
As	-	-	-	1.99
Sn	0.99	-	-	1.93
sum	4.00	1.99	0.99	15.01

Abbreviations tables 8 and 9:

vys; vysotskite; at: atokite; gng: guanglinite;zv:zvyaginsevite; sk: Skaergaardite; (Pt,Fe): alloy; un: Pd11As2Sn2, bn: bornite; cp: chalcopyrite; chl: chlorite

PLATES

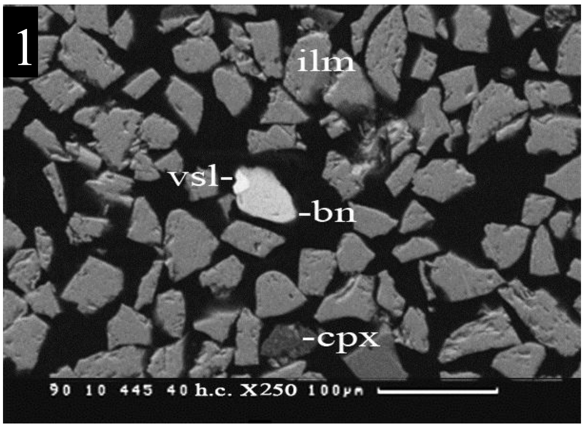
Plate 1

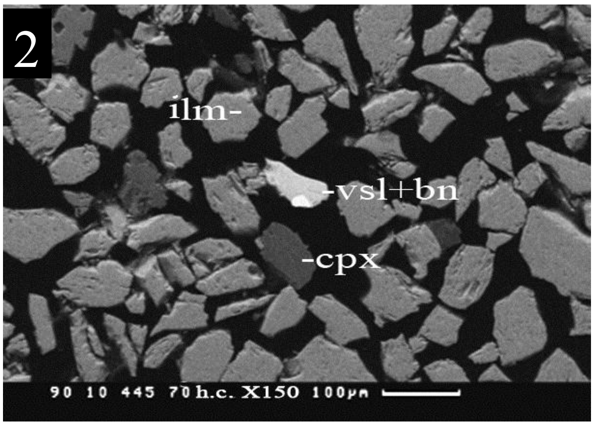


Relationships of rock-forming minerals, Fe-Ti oxides amd PGMs in sample 90-10 445; polished section; SEM-images (BIE).

Abbreviations: Pl: plagioclase; cpx-opx: clinopyroxenes with orthopyroxene exsolutions; ol; olivine; srp: serpentine; timt: tiitanomagnetite, mt: magnetite; ilm: ilmeniite; bn: bornite.

Plate 2

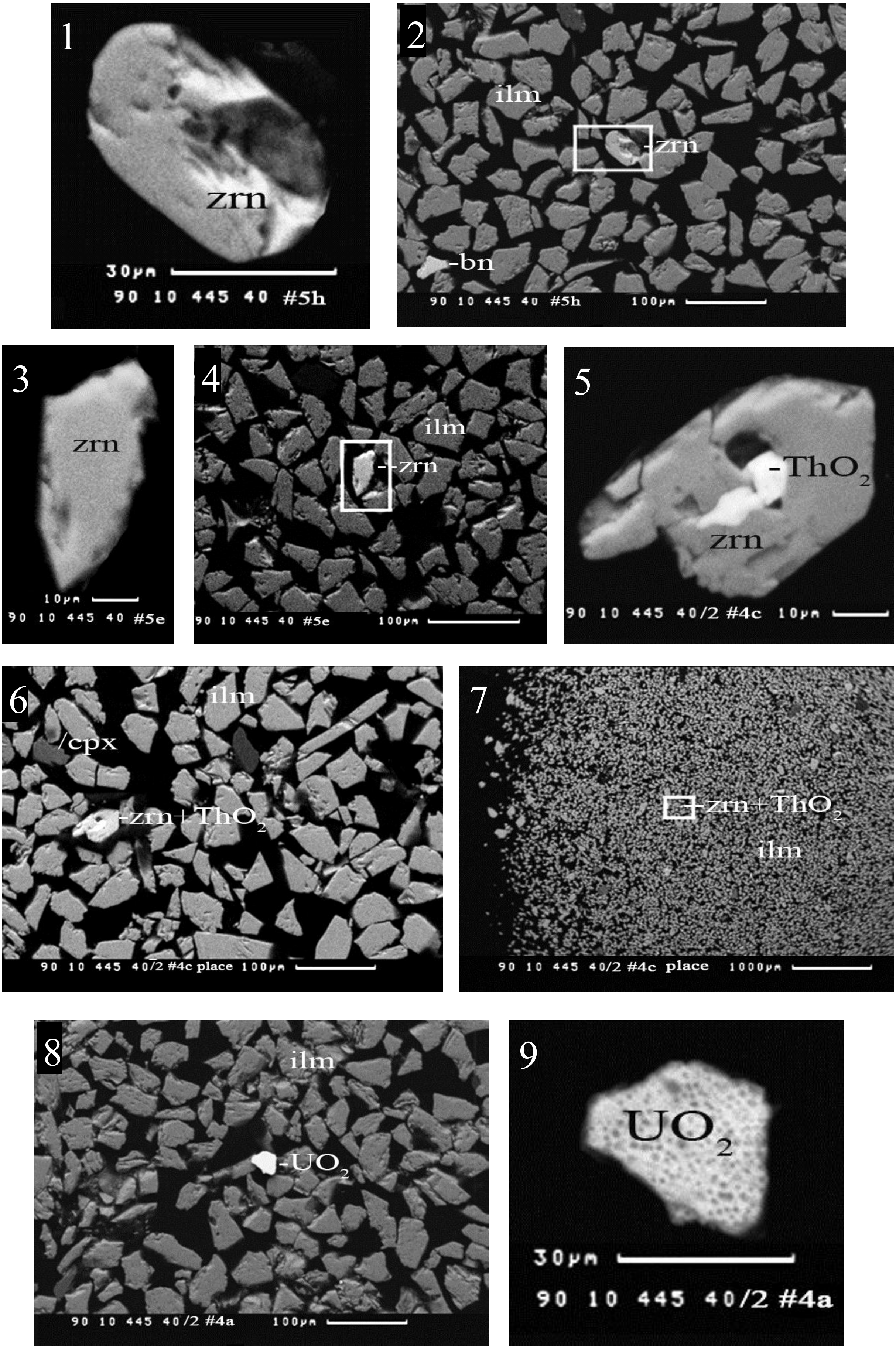




Polished sections of heavy mineral HS-concentrates, sample 90-10 445, SEM-images (BIE): 1) <40 µm fraction, and 2) 40-70µm fraction.

Abbreviations: ilm: ilmenite; cpx: clinopyroxene, bn: bornite; vsl: vasilite

Plate 3



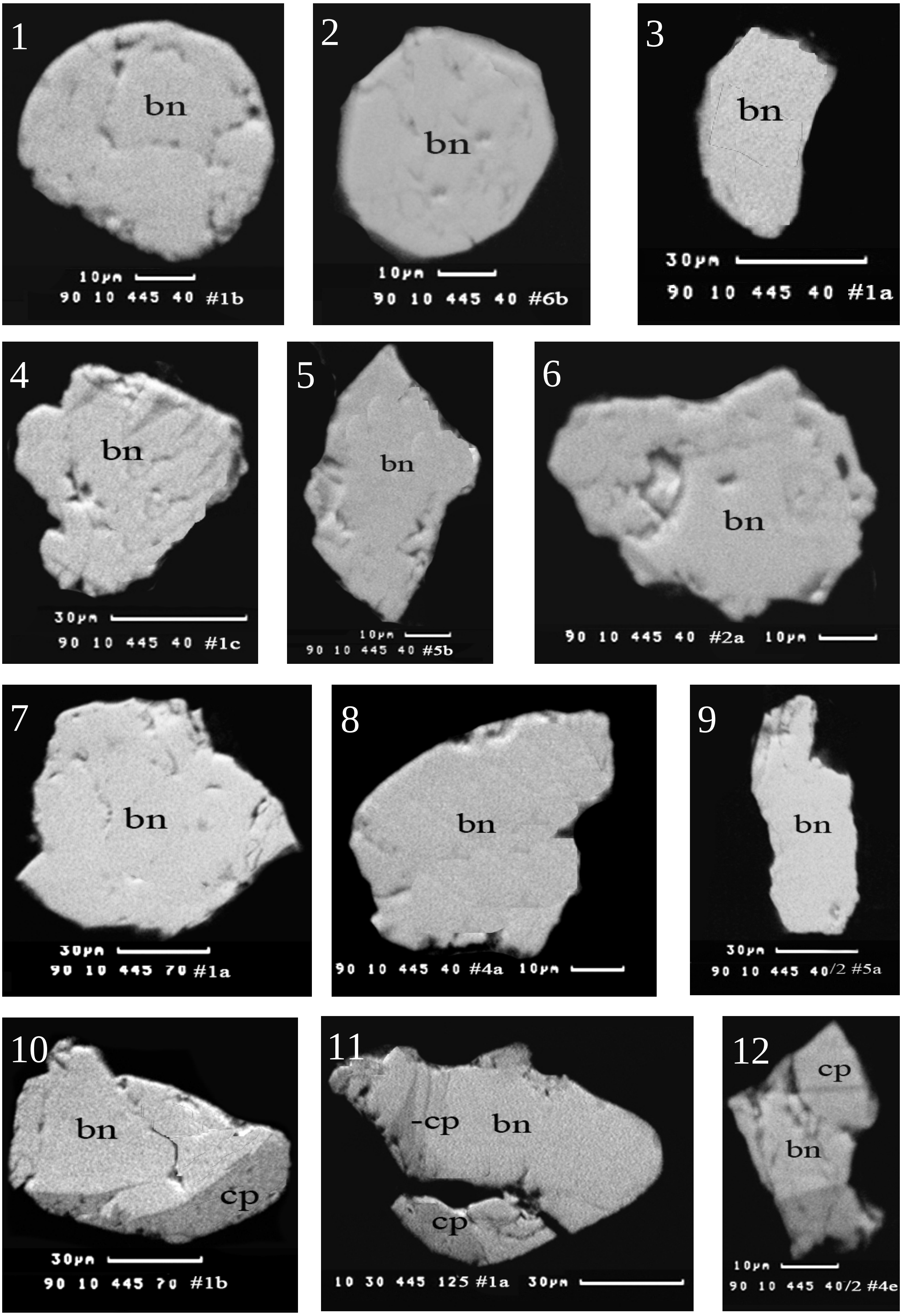
Zircon (zrn) and uraninite (UO_2) grains in the heavy mineral HS-concentrates of sample 90-10 445; polished sections, SEM-images (BIE).

Abbreviations: zrn: zircon; UO_2: uraninite; ThO_2: thorionite; ilm: ilmenite

Plate 4

Grains of sulphide mineralization from oxide-rich tholeiitic gabbros, sample 90-10, 445 (1-24); polished sections of grains from the heavy mineral HS-concentrates; SEM-images (BIE).

Abbreviations: bn: bornite; cp: chalcopyrite; chal: chalcosine: dgn: digenite; po: pyrrhotite; pn: pentlandite, and cpx-opx. Clinopyroxene with orthopyroxene exsolutions.


1
bn
10µm
90 10 445 40 #1b
2
bn
10µm
90 10 445 40 #6b
3
bn
30µm
90 10 445 40 #1a
4
bn
30µm
90 10 445 40 #1c
5
bn
10µm
90 10 445 40 #5b
6
bn
90 10 445 40 #2a 10µm
7
bn
30µm
90 10 445 70 #1a
8
bn
90 10 445 40 #4a 10µm
9
bn
30µm
90 10 445 40/2 #5a
10
bn
cp
30µm
90 10 445 70 #1b
11
-cp
bn
cp
10 30 445 125 #1a 30µm
12
cp
bn
10µm
90 10 445 40/2 #4e

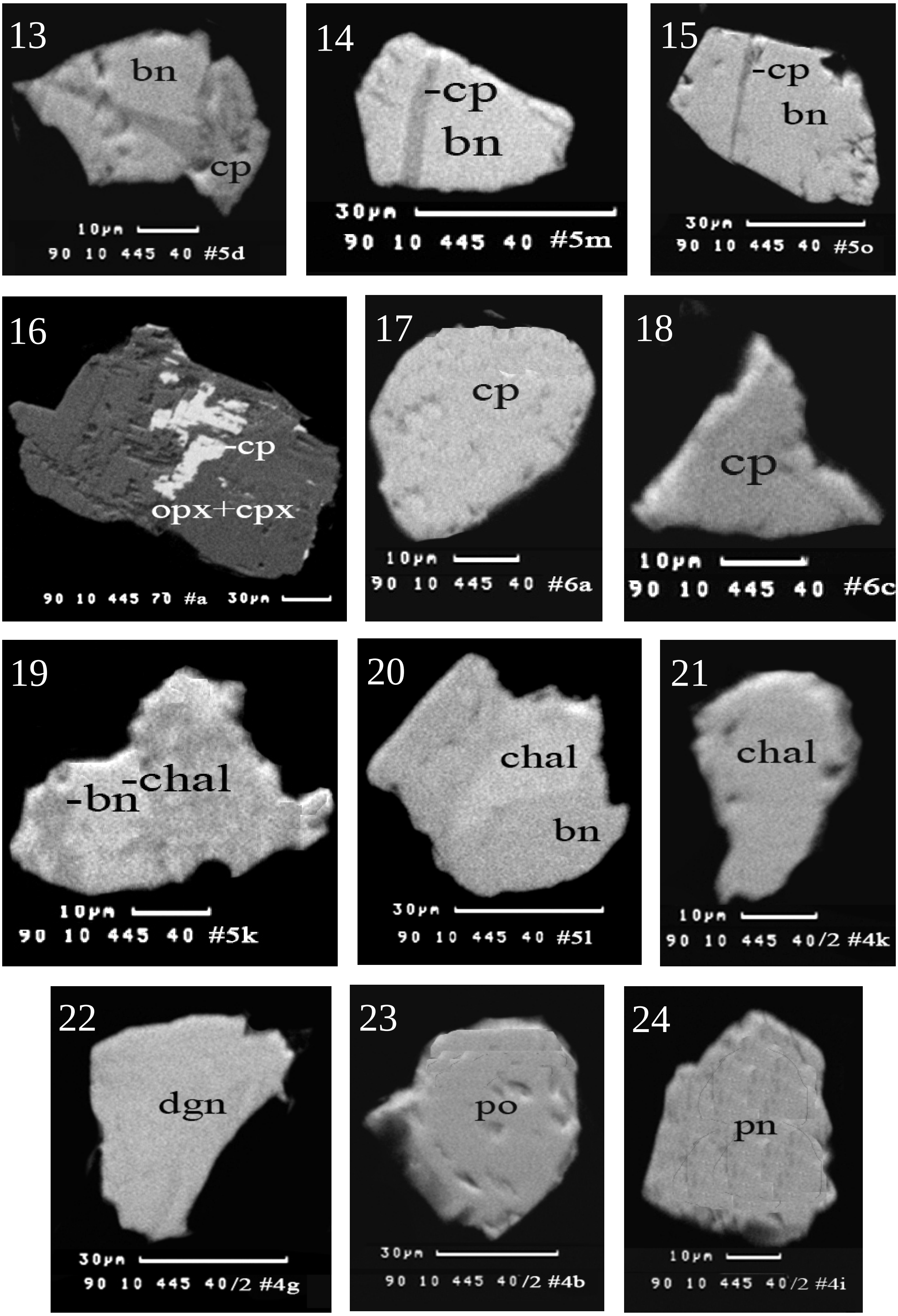
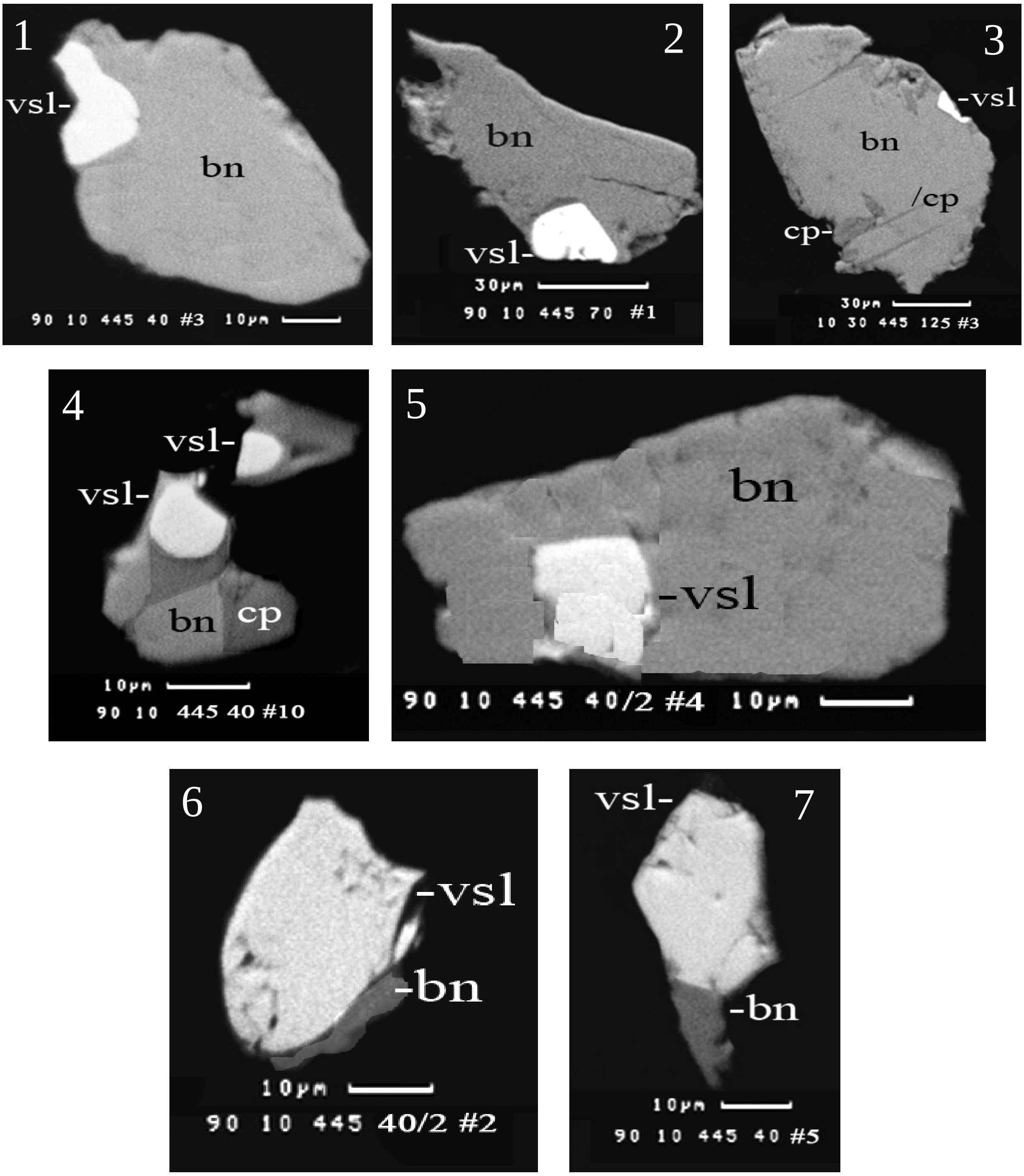

13
bn
cp
10µm
90 10 445 40 #5d
14
-cp
bn
30µm
90 10 445 40 #5m
15
-cp
bn
30µm
90 10 445 40 #5o
16
-cp
opx+cpx
90 10 445 70 #a 30µm
17
cp
10µm
90 10 445 40 #6a
18
cp
10µm
90 10 445 40 #6c
19
-bn
-chal
10µm
90 10 445 40 #5k
20
chal
bn
30µm
90 10 445 40 #5l
21
chal
10µm
90 10 445 40/2 #4k
22
dgn
30µm
90 10 445 40/2 #4g
23
po
30µm
90 10 445 40/2 #4b
24
pn
10µm
90 10 445 40/2 #4i

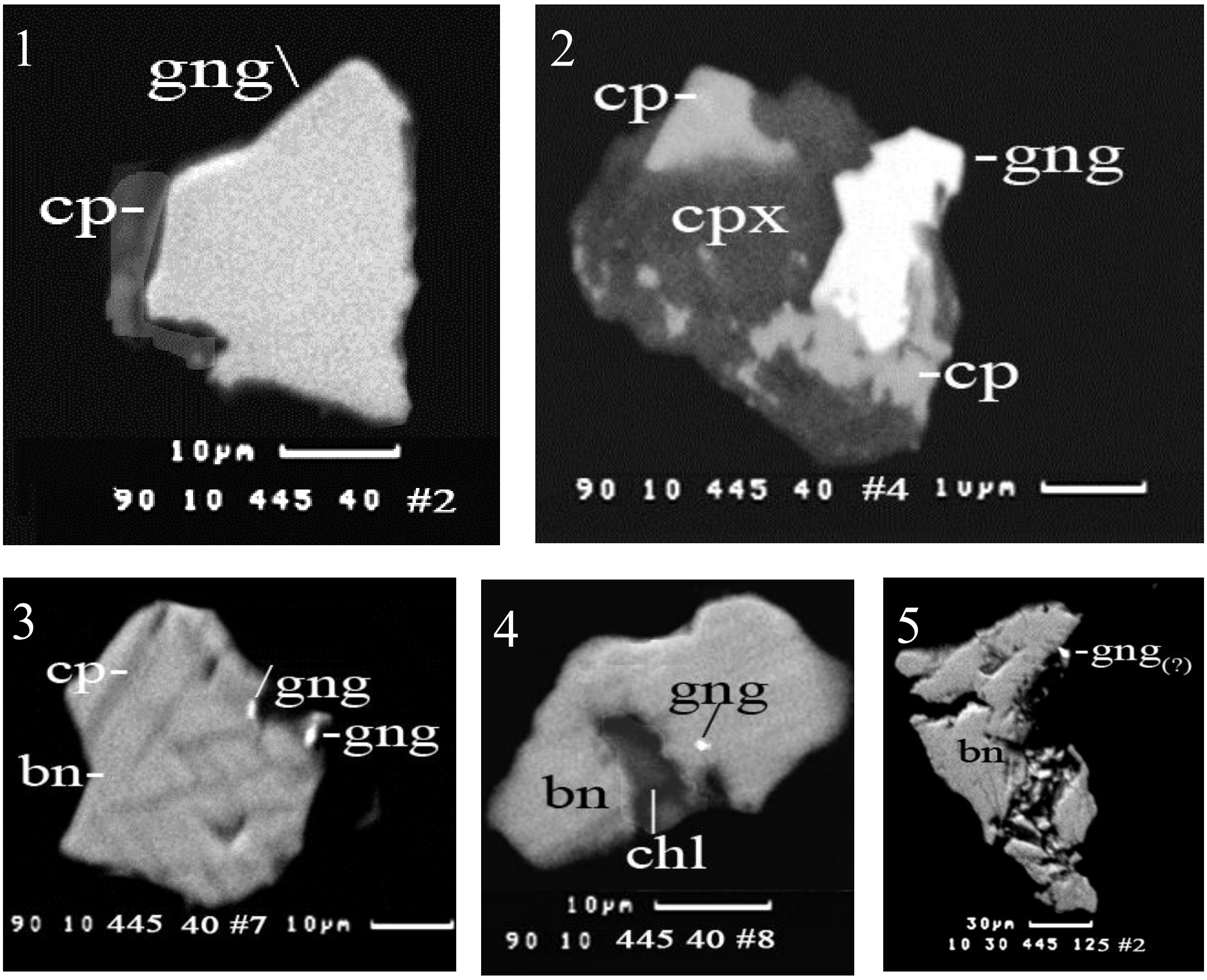
Plate 5



Grains of vasilite in the heavy concentrates of the sample 90-10 445; polished sections; SEM-images (BIE).

Abbreviations:vsl: vasilite; bn: bornite; cp: chalcopyrite

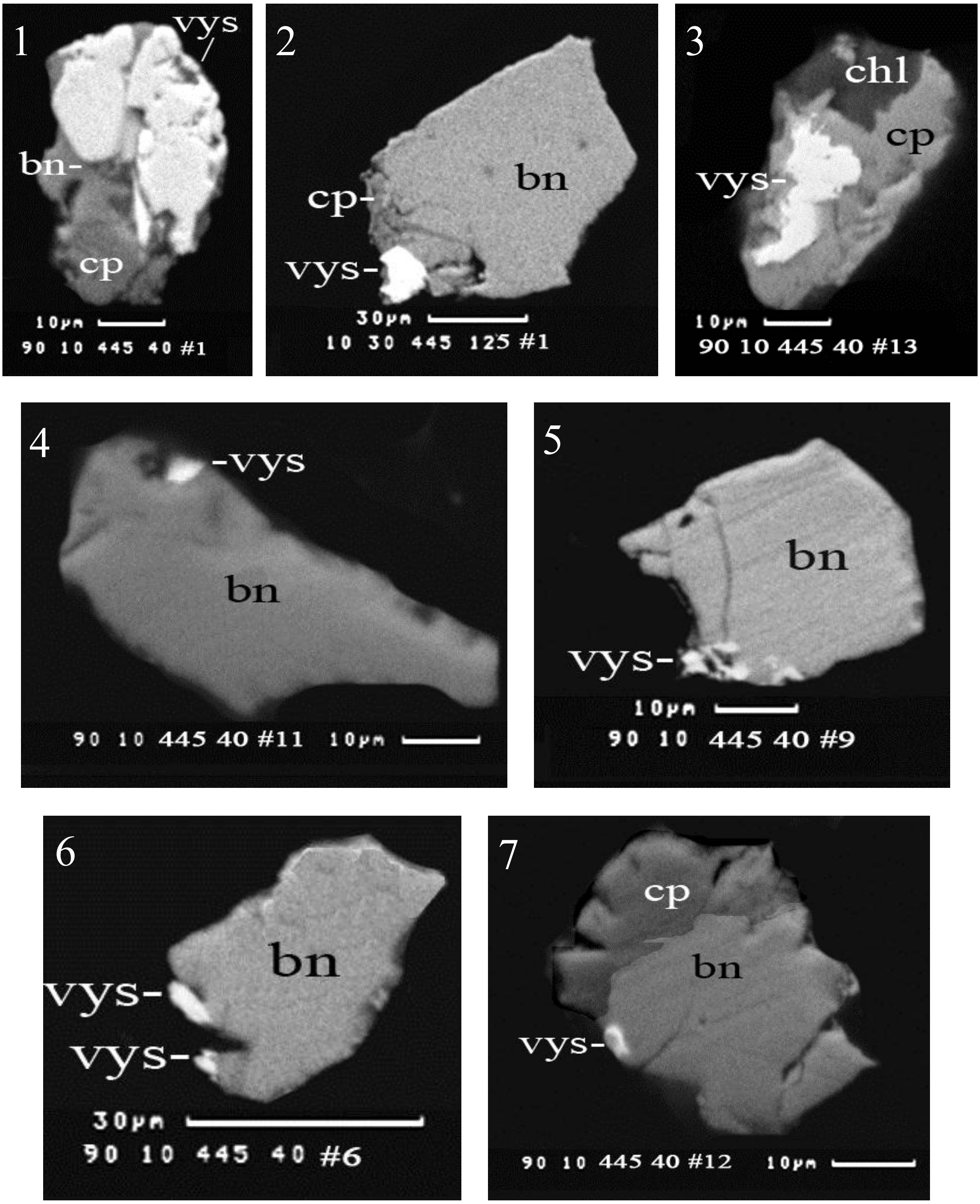
Plate 6



Grains of guanglinite in the heavy mineral concentrates of sample 90-10 445 (1-5); polished sections; SEM-images (BIE).

Abbreviations: gng: guanglinite; cp: chalcopyrite; bn: bornite; cpx: clinopyroxene; chl: chlorite

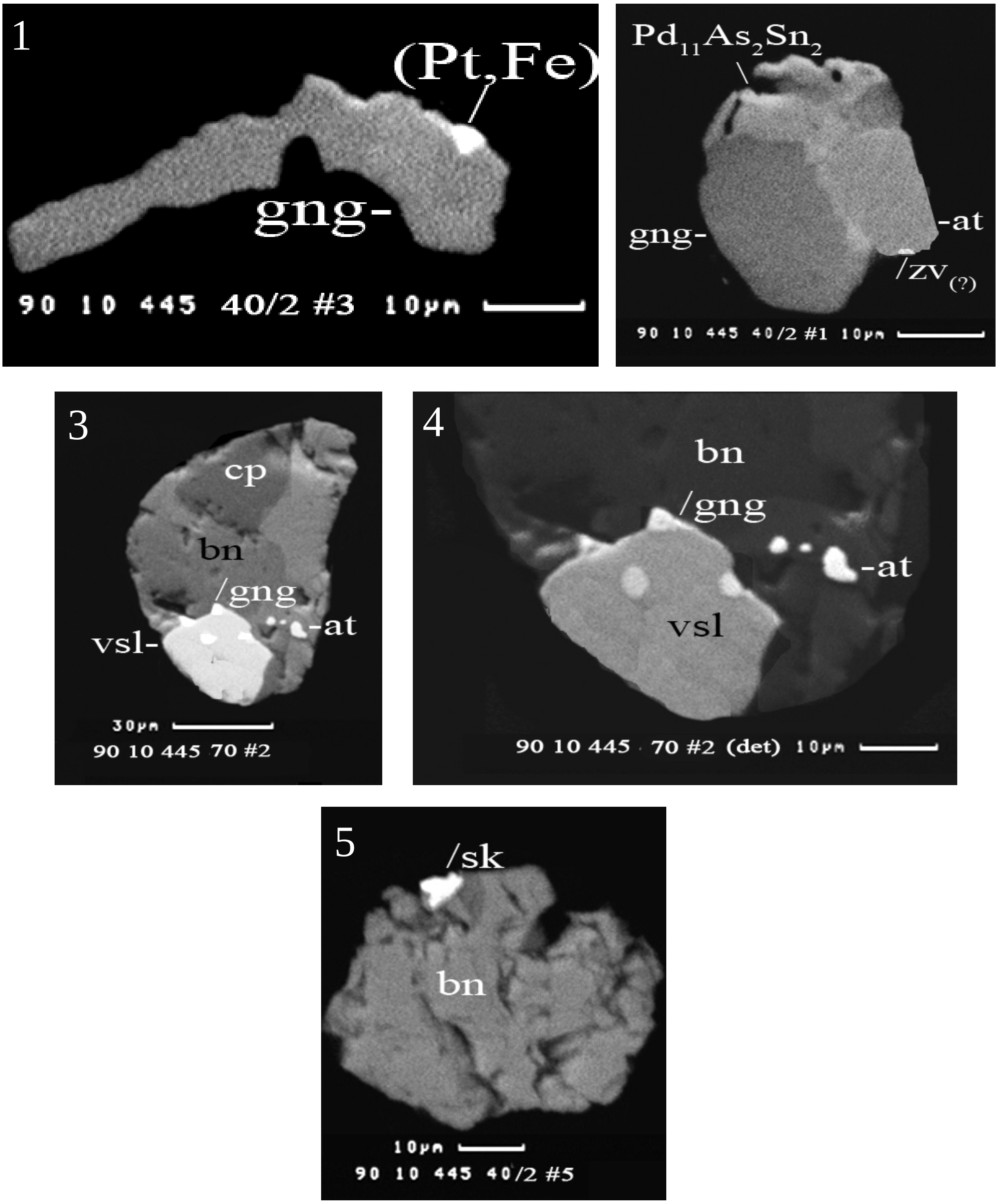
Plate 7



Grains of vysotskite in the heavy concentrates of sample 90-10 445; polished sections; SEM-images (BIE).

Abbreviations: vys: vy vys: vysotskite; bn: bornite; cp: chalcopyrite; chl: chlorite

Plate 8



Grains of (Pt,Fe) alloy, atokite, unnamed $Pd_{11}As_2Sn_2$, zvyagintsevite (?) and skaergaardite in the heavy concentrates of sample 90-10 445; polished sections; SEM-images (BIE).

Abbreviations: gng: guanglinite; (Pt,Fe) alloy; $Pd_{11}As_2Sn_2$: unnamed mineral; at: atokite; zv: zvyagintsevite; vsl: vasilite; sk: skaergaardite; bn; bornite; cp: chalcopyroxene