DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2010/73

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

Part 8: Sample 90-18 972

Nikolay S. Rudashevsky, Vladimir N. Rudashevsky
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MINISTRY OF CLIMATE AND ENERGY

G E U S

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Abstract

The report presents the results of mineralogical investigations of the sample 90-18 972 from the Pd2a level in the Platinova reef in the AU-PGE mineralization of the Skaergaard intrusion. The bulk sample covers the interval from 972 to 973 metres in core 90-18. Assays give 745 ppb Pd, 114 ppb Au, and 39 ppb Pt for this interval.

The sample (800 g) was crushed in small portions using a shatter box with small cavities (200 ml) for short periods (0.2-0.4 min) and sieved to remove the fine fraction (sieve -125 μm) after each crushing session. The residual coarse fraction >125 μm was re-crushed again 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 processed through wet magnetic separation.

The non-magnetic parts of every fraction from the sample 90-18 972 were hydroseparated by means of the computer controlled device CNT HS-11. As the result, the monolayered polished sections were produced from the heavy HS-concentrates of each fraction. These polished sections (and one polished section of the primary rock) were investigated under the scanning electron microprobe. All magnetic fractions did not contain precious metal grains.

Gabbro of the sample 90-18 972 has characteristic structure of a reaction relationship between cumulus and inter cumulus phases: rims of olivine at the boundaries between accumulated grains of Fe-Ti-oxides and two-pyroxenes. Olivine is preserved in these rimes in the form of rare relicts. As a rule, it is replaced by talc (ferrosaponite) + magnetite.

The HS-concentrates contain numerous sulphide grains identified as sulphide droplets. They are formed by Cu-Fe-sulphides – chalcosine (sometimes digenite) and bornite as exsolution texture. Several of these droplets and sulphide grains contain inclusions of several PGE and Au minerals.

A representative selection of PGMs and gold minerals (60 grains) were studied in detail. The main precious metal minerals are vysotskite – 46.7 vol. %, vasilite –20.8 vol. % and gold minerals (unnamed Au_3Cu+tetra-auricupride) – 15 vol. %. These minerals are followed by 7-9 minor PGMs (~17 % of all PGE and gold minerals of the sample): skaergaardite Pd(Cu,Fe,Zn) (4.8 vol. %), arsenopalladinite $(Pd,Cu)_8As_3$ (4.3 vol. %), palladoarsenide $(Pd,Cu)_2As$ (2.2 vol. %), keithconnite $(Pd,Cu)_3(Te,As,Sn)$ (3.5 vol. %), atokite Pd_3Sn (~1 vol. %), unnamed Pd_3Ag_2S? (~1% vol. %), (Pt,Fe,Pd,Cu) alloy (0.2 vol. %), unnamed $(Pd,Hg,Ag)_2S$ (0.3 vol. %) and (Pd,Cu,Pb) alloy (0.3 vol. %). In addition, grains of (Ag, Cu) alloy were also identified in the heavy mineral HS concentrates

The grain size of PGE and Au minerals (ECD) varies from 1 to 23 μm, but fine grained particles are dominating with an average grain size of 10.5 μm.

The average composition of vysotskite (from 17 analyses) is (wt. %):
Pd: 72.8, Pt: 0.1, Cu: 1.9, Ni: 0.7, Fe: 0.6, S: 23.6, Total: 99.7; and corresponding to:

$$\mathbf{(Pd_{0.93}Cu_{0.04}Ni_{0.02}Fe_{0.01})_{1.00}S_{1.00}.}$$

The average composition of vasilite (from 8 analyses) is (wt. %): Pd: 72.0, Cu: 14.2, Fe: 0.8, S: 12.8, Total: 99.9; and corresponding to:

$$\mathbf{Pd_{11.87}(Cu_{3.90}Fe_{0.25})_{4.15}S_{6.99}.}$$

The estimated bulk composition of the sample (assays of whole rock in brackets) is (ppb): Pd 770 (745), Au 130 (114), Pt 3 (39). Pd is concentrated in vysotskite, vasilite and other Pd PGMs (740 ppb), less in gold minerals (30 ppb). Au is distributed between its own minerals (unnamed Au_3Cu and tetra-auricupride). Pt is concentrated partly in vysotskite and in its own Pt alloys. The content of Pt in the sample is close to the sensitivity level of the current mineralogical analysis.

The majority of the determined grains of PGE and Au minerals have single paragenesis together with Cu-Fe sulphides.

Introduction

The report describes the mineralogy of sample 90-18 972 from Pd2a level in the “Platinova Reef” of the Au-PGE mineralization in the Skaergaard intrusion. An introduction to the mineralization is given in Nielsen et al. (2006).

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 a primary gabbro. Monolayered polished sections of HS concentrates and one polished section of gabbro have been studied using electron microscopy and electron microprobe analysis (Camscan-4DV, Link AN-10 000). The report gives description of the grain characteristics, the parageneses and the compositional variations within the identified groups of minerals, alloys, sulphide droplets and matrix gabbro.

Sample 90-18 972

Sample 90-18 972 was collected as a representative bulk sample between 972 and 973 meters in BQ drill core #90-18 (details on drill core 90-18 in Watts, Griffith and McOuat (1991). Assays for the 972-973m interval give 745 ppb Pd, 114 ppb Au, and 38 ppb Pt for this interval.

The core has previously been sampled for other purposes. The sample collects 1/3 of the diameter of the preserved core.

Mineralogical investigation

Introduction

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003): PGE and sulphide phases of the precious metal mineralisation 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 HS concentrates, enriched by precious metal minerals (Plate 2) were received by means of new patented model of computer controlled Hydroseparator CNT HS-11 and newly patented glass separation tube (GST) (Rudashevsky, Rudashevsky, 2006, 2007) – see www.cnt-mc.com.

The remaining core material was crushed to –125 μm. After complete grinding, the sample was passed through standard sieves with water (wet sieving): <40 μm (326.1 g) , 40-63 μm (204 g), 63-80 μm (20.4 g), 80-125 μm (190.4 g). After wet magnetic separation, the powdered fractions <40 μm, 40-63 μm, 63-80 μm, 80-125 μm were passed through hydroseparator CNT HS-11. Monolayered polished sections were produced from all heavy HS-concentrates.

Results

Rock forming minerals and sulphide mineralogy

Silicates and oxides

The silicates and oxides related to sulphides are: 1) *plagioclase*, An_{42-47} (Table 1, analyses 1, 2); 2) *monoclinic ferrous pyroxene*, Mg# = 0.62-0.63 (Table 1, analyses 3, 4); 3) *orthorhombic ferrous pyroxene*, Mg# = 0.50-0.51 (Table 1, analyses 5, 6); 4) *fayalite*, Mg# = 0.41-0.42 (Table 1, analyses 7-9); Fe-Ti oxides including 5) *ilmenite* (Table 1, analyses 10-12) and 7) *titaniferous magnetite* (Table 1, analyses 13, 14). Monoclinic and orthorhombic pyroxenes form typical exsolution textures (see Plate 1, #*1-3*).

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, *1, 3*). Gabbro of the sample 90-18 972 has characteristic structure of a reaction relationships of cumulus and inter cumulus phases: rims of fayalite at the boundaries between accumulated grains of Fe-Ti-oxides and two-pyroxenes (Plate 1, #*1*). However, olivine inside these rims is preserved only as relicts. As a rule, olivine is replaced by aggregates of talc (ferrosaponite) + magnetite) – (see Plate, 1, #*1*; Table 1, analyses 15-19).

In the heavy mineral HS concentrate 2 grains of baddeleyite were identified (~30-50 μm) – Plate 3. They can be used in the following geochronological investigations for dating the studied Pd2a ore horizon.

Sulphides

Matrix gabbro is relatively poor in sulphides. In the investigated polished section one bornite aggregate was found only as inclusion in ilmenite grain (Plate 1, #*3, 4*).

The nonmagnetic heavy concentrates are ilmenite-rich products (> 97 %) enriched by grains of sulphides and PGMs. The sulphide grains are represented by droplet-like microglobules (Plate 4, #*1-16*; *31-34* etc) or irregular aggregates (Plate 4, #*17-30, 35-37* etc) up to 0.1 mm.

The following rock-forming minerals often are found in the marginal parts of sulphide grains or surrounding these grains: clinopyroxenes (Plate 5, #*25*), ilmenite (Plate 4, #*29, 30*; Plate 6, #*3, 4);* talc (Plate 4, #*35, 36*; Plate 5, #*16*; Plate 6, #*7*), chlorite (Plate 4, #*31-34, 37*; Plate 5, #*15;* Plate 6, #*3, 4, 7*; Plate 7, #*5, 9*; Plate 8, #*8, 9*), tremolite (Plate 7, #*7*), hornblende (Plate 8, #*6*), epidote (Plate 5, #*24*) and calcite (Plate 4, #*31*; Plate 5, #*16*).

Matrix gabbro of the sample 90-18 972 is enriched in volatile components (first of all H_2O) that were found in the studied polished section (see Plate 1, #*1*). Such minerals (chamosite, talc, epidote, hornblende, tremolite, calcite) were identified in the heavy mineral concentrates in composition of several sulphide globules also containing precious metal minerals.

The sulphide grains and aggregates are dominantly (> 95 %) composed of bornite and chalcosine (sometimes digenite) - (see Plates 2-8). Bornite and chalcosine form classical exsolution textures inside sulphide micro-globules and grains (see Plate 4, *1-28, 30-34, 36, 37* etc.).

Chemical composition of chalcosine (Table 2, analyses 1, 5, 9, 10, 12, 16, 18, 20), bornite (Table 2, analyses 2-4, 6-8, 11, 13, 15, 17, 19, 21) and digenite (Table 2, analysis 14) are close to stoikiometric.

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

Recovery

Only one fine PGM grain of (Pd,Cu,Pb) composition 5 μm in size was found during SEM studies of the polished section of gabbro (sample 90-18 972). This PGM together with bornite were included in ilmenite (Plate 1, #*3, 4*; see Table 11, analysis 12).

The heavy mineral concentrates have yielded many precious metal grains. Their representative selection of 60 grains of a wide size range (from <40 μm up to 80-125 μm) was studied in detail. In total, 12 different PGE and Au minerals are documented in the sample 90-18 972. They include (Table 3):

1. *vysotskite* (Pd,Cu,Ni,Fe,Pt)S – 30 grains,
2. *vasilite* $Pd_{12}(Cu,Fe)_4S_7$ –11 grains
3. *tetra-auricupride* (Au,Pd)(Cu,Fe) – 2 grains,
4. *unnamed* $(Au,Pd)_3$ Cu – 4 grains,
5. *keithconnite* $(Pd,Cu,Fe)_3(Te,As,Sn)$ –9 grains,
6. *arsenopalladinite* $(Pd,Cu,Fe)_8As_3$ – 5 grains,
7. *palladoarsenide* $(Pd,Cu,Fe)_2As$ – one grain,
8. *atokite* $(Pd,Cu,Fe)_3Sn$ – 2 grains,
9. *skaergaardite* (Pd,Au)(Cu,Fe,Zn) – 2 grains,
10. *(Pt,Fe,Pd,Cu)* alloy – one grain,
11. *unnamed* Pd_3Ag_2S?– 3 grains,
12. *unnamed* $(Pd,Hg,Ag)_2S$ – one grain,
13. *unnamed* (Pd,Cu,Pb) – one grain.

The volumetric proportions are calculated from the area of grains of these minerals (Table 3 and Fig. 1). Besides 4 grains of (Ag,Cu) alloy were also found in polished sections of the heavy HS concentrates.

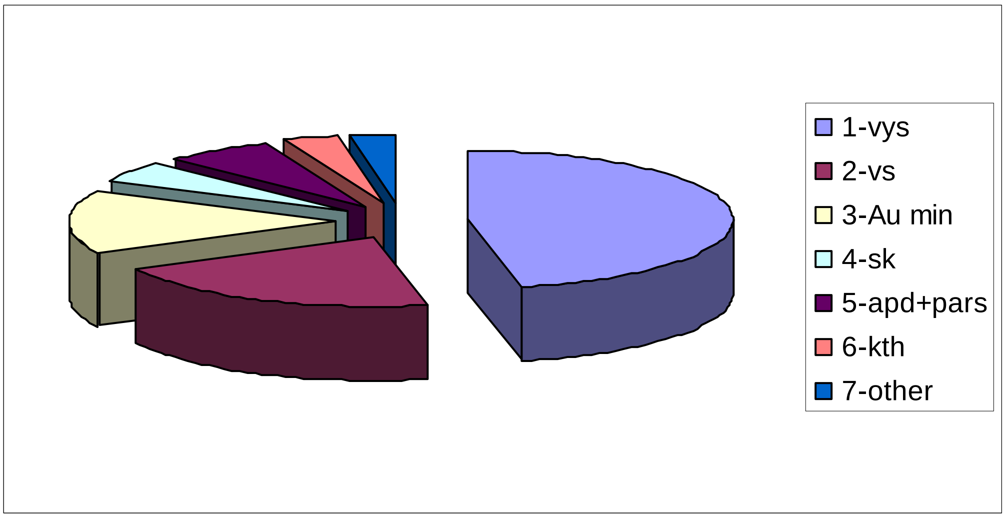

Fig. 1. Relative contents of PGE and Au, the sample 90-18 972 (see Table 3)

1 – vysotskite, 46.7 vol. %; 2 – vasilite, 20.8 vol. %; 3 – Au minerals (tetra-auricupride and unnamed Au_3Cu) 15.0 vol. %; 4 – skaergaardite, 4.8 vol. %; 5 – Pd arsenides (arsenopalladinite + palladoarsenide), 6.5 vol. %; 6 – keithconnite, 3.5 vol. %; 7 - other PGMs - 2.7 vol. %.

Grain size

Grain sizes are measured by the effective diameter of the grains (ECD) by means of imageJ software. They vary from 1 to 23 µm with an average of 10.5 µm (Table 4; Fig. 2). Grain sizes of (Ag,Cu) alloy are from 14 to 34 µm, in average 24 µm.

The histogram of grain sizes (Fig. 2) shows the lognormal distribution for the statistical selection (n=60). According to this histogram, size of PGE and Au mineral grains are distributed as follows:

	Number of grains
0-5 µm	15
5-10 µm	14
10-15 µm	15
15-20 µm	9
20-25 µm	7

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 2-8). Grains have not been broken during production of the concentrates. The largest proportion of PGM grains is as inclusions in Cu-Fe sulphides globules and grains.

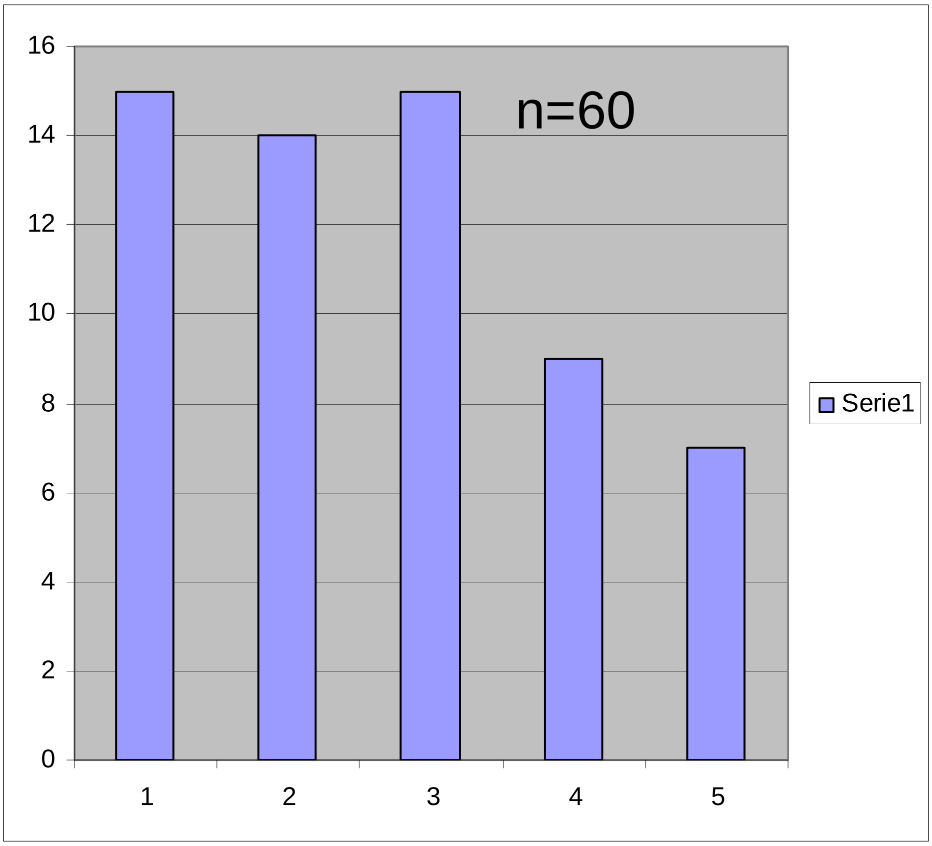

Fig 2. Histogram of size of precious metal mineral grains (n=60), extracted in the heavy concentrates of the sample 90-18 972. In abscissa: 1 – 0-5 µm, 2 – 5-10 µm, 3 – 10-15 µm, 4 – 15-20 µm, 5 – 20-25 µm.

Petrographic observations

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 the most important information on the mineral genesis. The concentrates provide full information for the reconstruction of the primary shapes and sizes of accessory minerals, together with their mineral paragenesis and relationships with the minerals of the matrix rock.

In the heavy concentrates of the sample 90-18 972 (n=60) the PGE and Au mineral grains occur in the following mineral associations (Fig. 3; Table 5):

Table 5. Different associations of PGE and Au mineral grains in heavy concentrates of the sample 90-18 972

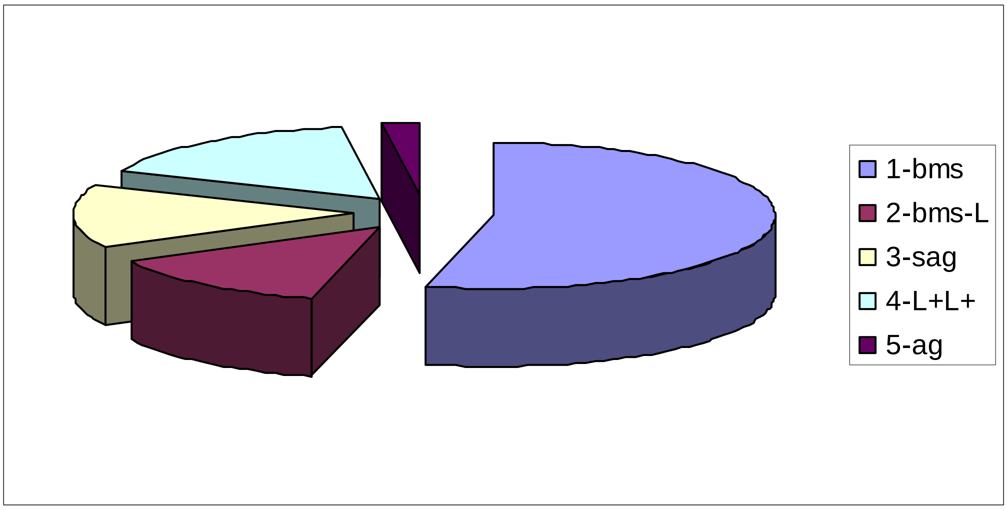

Fig. 3. PGE and Au minerals grouped by associations, sample 90-18 972; see Table 5.

1-54 vol. % **(bms)** – PGE and Au minerals attached to base metal sulphides; 2 – 13.3 vol. % (**bms-L)** PGE and Au minerals attached to base metal sulphides but less than 10 %; 3 – 14.2% (**sag),** PGE and Au minerals attached to sulphides and gangue; 4**-** 16.3 % (**L+L$^+$**) completely liberated (free) particles of PGE and Au minerals; 5 – 2.2 % (**ag**), PGE and Au minerals attached to gangue.

Association	PGM-grains, number	PGM-grains, vol. %
bms	41	54
bms-L	4	13.3
L	2	5.7
L$^+$	2	10.6
sag	9	14.2
ag	2	2.2

Bms - intergrowths with base metal sulphides (bornite, chalcosine); **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 (clinopyroxenes, ilmenite, chlorite, talc, epidote, tremolite, hornblende) attached to PGMs; **ag** - PGMs attached to gangue (clinopyroxene).

The input of completely liberated precious metal mineral grains (**L+L$^+$**) from the heavy mineral concentrate is 16.3%. However, their grains attached to bms (**bms**+**bms-L**+**sag** associations) are dominating which corresponds to 81.2 % (see Fig 3), whereas 2.2 % of PGMs only are attached to gangue (**ag** association).

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

1. vysotskite (Plate 5);

2. vasilite (Plate 6);
3. other Pd minerals (Plate 7) rare in the sample 90 18, 972;
4. Au, Pt and Ag alloys (Plate 8).

Description and chemistry of precious metal minerals

Vysotskite (Pd,Cu,Ni)S

Description

Vysotskite is one of the main Pd mineral in heavy concentrates of the sample 90-18 972 (46.7 vol.%). It is found in the heavy mineral concentrates in the following forms:

1. dominant, intergrowths with base metal sulphides (bornite and chalcosine) - **bms** (Plate 5, #*3-14, 17-23, 26, 27*; Plate 8, #*2);* **bms-L** (Plate 5, #*28, 29*);
2. intergrowths with sulphide and gangue (ilmenite, chlorite, talc, calcite) – **sag** (Plate 5, #*1, 15, 16, 24;* Plate 7, #*9, 10*);
3. intergrowths with sulphides and other PGMs – unnamed $(Pd,Hg,Ag)_2S$ (Plate 7, #*9, 10*) or Au minerals – with tetra-auricupride (Plate 8, #*2*);
4. inergrowths with gangue (**ag**) – with clinopyroxene (Plate 5, #*25*).

The vysotskite-bearing sulphide grains occur very often as droplet-like (Plate 5, #*1-5, 10, 14, 16, 18 etc*); or irregular-shaped grains (Plate 5, #*11-13, 17,19-24 etc*).

Vysotskite grains occur as:

1. fine (1-5 μm) droplet-like grains with the rounded outlines (Plate 5, #*3-5, 7, 9, 11, 13-15* etc) or irregular shape (Plate 5, #*2, 6, 10, 12, 21* ets);
2. irregular shape grains >10 μm in size (Plate 5, #*16-20, 22-24, 26-29* etc.).

The relationships of vysotskite and sulphide phases are following:

1. vysotskite grains or aggregates localized at the margin of sulphide globules or aggregates (Plate 5, #*2, 4, 5, 7, 10-13, 17, 18, 20-22* etc*);*
2. vysotskite aggregates, distributed by volume of sulphide aggregates (Plate 5, #*3, 6, 9, 14-16, 23, 24* etc*.).*

Grain sizes of vysotskite (30 grains) are 1-23 μm with an average of 10 μm (Table 3).

Mineral chemistry

The chemical composition of vysotskite has been determined in 16 analyses of 16 different grains (Table 6, analyses 1-16). Average composition of vysotskite (Table 6, analysis 17) is the following (wt. %): Pd 72.8, Pt 0.1, Cu 1.9, Fe 0.6, Ni 0.7, S 23.6, Total 99.7. The composition corresponds to the formula $(Pd_{0.93}Cu_{0.04}Ni_{0.02}Fe_{0.01})_{1.00}S_{.1.00}$ Typical admixtures in vysotskite are following: Cu up to 5.3 % (Table 6, analysis 1), Ni up to 4.5 % (Table 6, analysis 11), Fe up to 1.3 % (Table 6, analysis 7), Pt up to 1.3 % (Table 6, analysis 14).

Vasilite $Pd_{12}(Cu,Fe)_4S_7$

Description

Vasilite is the second main Pd mineral in heavy concentrates of the sample 90-18 972 (20.8 vol.%). It is found in the heavy mineral concentrates in the following forms:

a) dominant, intergrowths with base metal sulphides (bornite and chalcosine) - **bms** (Plate 6, #*5, 6, 10*; Plate 7, #*11);* **bms-L** (Plate 6, #*9, 11*);
b) intergrowths with sulphide and gangue (ilmenite, chlorite, talc) – **sag** (Plate 6, #*3, 4, 7*);
c) intergrowths with sulphides and other PGMs – keithconnite (Plate 6, #*3-6*), unnamed Pd_3Ag_2S? (Plate 7, #*11*);
d) liberated grain intergrowth with other PGM (**L^+**) - skaergaardite-(Au)? (Plate 6, #*8*).

The vasilite-bearing sulphide grains occur often as droplet-like (Plate 6, #*1-6*) or irregular-shaped grains (Plate 6, #*7-11* etc).

1. Vasilite grains and aggregates occur as droplet-like with the rounded outlines (Plate 6, #*1, 2, 5, 6, 10*) or irregular shape outlines (Plate 6, #*3, 4, 7-9, 11*).
2. Vasilite grains or aggregates localized as a rule at the margin of sulphide globules or aggregates (Plate 6, #*1-6, 7, 10*).

Grain sizes of the vasilite (11 grains) are 4-20 μm with an average of 12 μm (Table 3).

Mineral chemistry

The chemical composition of vasilite has been determined in 8 analyses of 8 different grains (Table 7, analyses 1-8). Average composition of vasilite (Table 7, analysis 9) is the following (wt. %): Pd 72.1, Cu 14.2, Fe 0.8, S 12.8, total 99.9. The composition corresponds to the formula $Pd_{11.86}(Cu_{3.90}Fe_{0.25})_{4.15}S_{.6.99}$ This composition is closed to stoikiometric for vasilite.

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

Skaergaardite is relatively rare PGM in heavy concentrates of the sample 90 18, 972 (4.8 vol. % of all PGE and Au minerals) –see Table 3. Only two skaergaardite-bearing grains found in the heavy mineral HS concentrates (see Table 3):

1. skaergaardite inclusion with round shape 20 μm in size at the margin of the bornite-chalcosine globule (Plate 7, #*14*; Table 8, analysis 1);
2. fine (2 μm) inclusion of skaergaardite-(Au)? (measured by qualitative microprobe analysis) in vasilite grain (Plate 6, #*8*).

Keithconnite $(Pd,Cu)_3(Te,As,Sn)$

Keithconnite is found in 9 PGM-bearing grains as fine (1-7 μm, in an average 5 μm; 3.5 vol. % of all PGE and Au minerals – see Table 3). Grains of this mineral are located in several different positions:

a) droplet like or irregular shape grains and aggregates of such grains at the margin zone of bornite-chalcosine globules (Plate 6, #*3-6*; Plate 7, # *7, 8*); keithconnite is often followed here by vasilite (Plate 6, #*3, 4, 6*) and, sometimes by H_2O-bearing minerals (tremolite –Plate 7, #*7*);

b) droplet like inclusions in vasilite grain which is included in bornite-chalcosine globule (Plate 7, #*6*);

c) inclusions in tetra-auricupride (Plate 8, #*2*);

d) inclusion inside margin zone of the Au_3Cu grain (Plate 8, #*4*);

e) intergrowths of keithconnite and Au-Cu-Pd-Ag alloy are located at the boundary between Cu-Fe sulphides and grains of the H_2O-bearing minerals (chlorite, hornblende; Plate 8, #*7-9*).

The chemical compositions of the keithconnite are given in the Table 8, analyses 4-10.

Arsenopalladinite $(Pd,Cu)_8As_3$

Arsenodalladinite is found in 5 PGM-bearing grains, 4.3 vol. % of all PGE and Au minerals; this mineral is 1-18 μm, in an average 7 μm in size – see Table 3. It is located in several different positions:

a) droplet like or irregular shape grains in bornite-chalcosine globules (Plate 7, #*1, 3, 4*); arsenopalladinite sometimes is accompanied by atokite (Plate 7, #*4*);
b) droplet like fine inclusions in vasilite grain (Plate 6, #*9*); this vasilite grain is accompanied by bornite;
c) completely liberated irregular grain (Plate 7, #*2*).

The chemical compositions of the arsenopalladinite are given in the Table 8, analysis 2.

Palladoarsenide (Pd,Cu)2As

Only one palladoarsenide grain irregular shape 14 μm in size (2.2 vol. % of all PGE and Au minerals) was found in heavy concentrates; this is grain-intergrowth of palladoarsenide, bornite and chlorite (see Table 3; Table 8, analysis 2: Plate 7, #*5*).

Atokite (Pd,Cu)3Sn

Only two atokite-bearing grains of irregular sharp (atokite is 1 vol. % of all PGE and Au minerals) were found in the heavy concentrates (Plate 7, #*4, 6*). Atokite (see Table 3; Table 8, analysis 11) is represented by fine (2-9 μm) inclusions in bornite (Plate 7, #*6*), or as integrowth (<10 μm in size) with arsenopalladinite enclosed in chalcosine-bornite globule (Plate 7, #*4*).

(Pd,Cu,Pb) alloy

Only one grain of (Pd,Cu,Pb) 6 μm in size was found in polished section of gabbro as inclusion in ilmenite together with bornite (Plate 1, #*3, 4*; see Table 3 and Table 8, analysis 12).

Gold minerals: tetra-auricupride (Au,Pd)Cu, unnamed $(Au,Pd,Ag)_3Cu$

Two grains of tetra-auricupride (tetra-auricupride is 4.2 vol. % of all PGE and Au minerals) were found in heavy mineral concentrates of the sample 90-18 972 (see Table 3; Table 9, analysis 1). They are 3 to 18 μm in size and have irregular shape. Tetra-auricupride grains contain keithconnite inclusions and are associated also with vysotskite and chalcosine (Plate 8, #*2*).

Four grains of unnamed mineral phase $(Au,Pd)_3Cu$ were found in the heavy mineral HS concentrates. $(Au,Pd)_3Cu$ has 10.8 vol. % of all PGE and Au minerals. Their grain size varied between 2 and 22 μm with an average of 14 μm and having irregular shape (see Table 3).

$(Au,Pd)_3Cu$ grains are represented in heavy mineral HS`concentrates by following forms:

1. completely liberated (**L**, Plate 8, # *5*), may be with inclusion of kethconnite (**L⁺**, Plate 8, #*4*);
2. intergrowth with clinopyroxene (**ag**, Plate 8, #*3*);
3. together with keithconnite, bornite, chalcosine and gangue (chlorite or hornblende; **sag**; Plate 8, #*6-9*).

Mineral chemistry

The composition of tetra-auricupride is in the Table 9 (analyses 1). The characteristic admixtures in this mineral are Pd 19.2 % and Fe 0.8 %. The chemical composition of unnamed $(Au,Pd)_3Cu$ has been determined in 4 analyses of 4 different grains (Table 9, analyses 2-5). Average composition of $(Au,Pd)_3Cu$ (Table 9, analysis 6) is the following (wt. %): Pd 10.7, Au 78.8, Cu 9.8, Fe 0.7, Total 100.0. The composition corresponds to the formula $(Au_{2.40}Pd_{0.61})_{3.01}(Cu_{0.92}Fe_{0.08})_{1.00}$. One grain of this mineral had Ag-rich composition (17.7 %; Table 9, analysis 7; see Plate 8, #6, 7). But this composition corresponds to the stoikiometric Au_3Cu too:

$$\mathbf{(Au_{1.52}\,Ag_{0.84}Pd_{0.64})_{3.00}(Cu_{0.88}Fe_{0.12})_{1.00}.}$$

(Pt,Fe,Pd,Cu) alloy

Only one grain of (Pt,Fe,Pd,Cu) alloy of irregular shape having 5 μm (0.2 vol. % of all PGE and Au minerals) was found in heavy concentrates; this grain-intergrowth of this alloy with bornite and chalcosine (see Table 3; Table 9, analysis 9: Plate 8, #1).

Unnamed Pd_3Ag_2S?

Three grains of unusual sulphide Pd and Ag are found in the margin parts of several bornite-chalcosine globules (Plate 7, #*11-13*). This mineral phase (~1 vol. % of all PGE and Au minerals; see Table 3; Table 7, analysis 11) occur as very fine (2-7 μm) inclusion in Cu-Fe sulphides. One grain was as intergrowth (<10 μm) of this sulphide and vasilite (Plate 7, #*11*). Such very fine grain sizes explain capability of just semi-quantitative analysis to be possible for determination of this unnamed sulphide (Table 7, analysis 11).

Unnamed $(Pd,Hg,Ag)_2S$

Only one grain of unnamed sulphide of $(Pd,Hg,Ag)_2S$ composition of irregular shape, 6 μm in size (0.3 vol. % of all PGE and Au minerals) was found in the heavy mineral HS concentrates. This grain-intergrowth of this sulphide and vysotskite with chlorite is localized at the margin part of bornite-chalcosine globule (see Table 3; Table 7, analysis 10; Plate 7, #*9, 10*).

(Ag,Cu) alloy

Several completely liberated grains of irregular shape of (Cu,Ag) alloys are found in the heavy mineral HS concentrates (Plate 8, #*10-13*). Grains of this alloy are 14-34 μm in size, with an average - 24 μm. The chemical composition of (Ag,Cu) alloy has been determined in 4 analyses of 4 different grains (Table 9, analyses 10-13). Average composition of the (Ag,Cu) alloy (Table 9, analysis 14) is the following (wt. %): Ag 92.2, Cu 6.1, Fe 0.9, Total 99.1, that corresponds to formula $(Pd_{0.89}Cu_{0.10}Fe_{0.02})_{100}$.

Bulk composition of PGMs of the sample 90-18 972

The relative concentrations of Pd, Au and Pt of the sample 90-18 972 can be calculated from the total concentration of precious metals, the determined recovery, the modal proportions and the chemical compositions (Tables 3, 5-8). The estimated bulk compositions of the sample (assays of whole rock in brackets) are (ppb): Pd 770 (745), Au 130 (114), Pt 3 (39). Pd is concentrated in vysotskite, vasilite and other Pd PGMs (740 ppb), less in gold minerals (30 ppb). Au is distributed between its own minerals (unnamed Au_3Cu and tetra-auricupride). Pt is concentrated partly in vysotskite and in its own Pt alloys. The Pt-content in the sample is close to the detection limits of mineralogical analysis.

Discussion

PGM-paragenesis

The extensive data shows that the dominant PGMs in the studied sample are Pd sulphides: vysotskite and vasilite (67.5%). In the subordinate quantities there are also Pd arsenides (arsenopalladinite+palladoarsenide, 6.5 %), gold minerals (unnamed Au_3Cu and tetra-auricupride, 15 %) and Pd tellurides (keithconnite, 3.5 %). All the observations and the inter-grain relations (Plates 5-8) suggest that at least all PGE and Au minerals are parts of a single paragenesis together with Cu-Fe sulphides.

In the composition of sulphide mineralization the dominant are microglobules and grains formed by bornite and chalcosine (sometimes - digenite), forming characteristic exsolution texture or bornite alone.

We should specially mention that in 3 studied samples describing drill-core 90-18 in composition of suphide mineralization (bornite-chalcosine + bornite + chalcosine grains = 100 %) the ratio of the grains, composed by bornite + exsolution aggregate bornite+chalcosine are following (from the bottom to the top):

a) sample 90-18 1012 –31%,
b) sample 90 18, 978 – 58 %,
c) sample 90-18 972 – 100 %.

In the studied sample often present volatile-bearing minerals – chlorite, talc, hornblende, epidote, calcite in the composition of sulphide grains. The wide distribution of H_2O-bearing minerals (talc, ferrosaponite), replacing fayalite, also have been documented in the composition of the matrix gabbro (see Plate 1, #*1*).

Besides the characteristic heavy metals of PD5 horizon (Pd, Pt, Sn, Pb, Au, Te), the mineralogy of the studied sample is also rich in As, Ag as well as Hg.

There is a tight association of gold minerals with keithconnite (Plate 8, #*2, 4, 6-9*) which is generally characteristic for Skaergaard gold mineralization.

The Cu-Fe sulphides, PGMs and gold minerals were synchronous and crystallized later than rock-forming minerals: plagioclase, clinopyroxene, orthopyroxene, olivine, ilmenite and titaniferous magnetite.

All above mentioned facts allow to suspect the replacement of heavy metals from bottom to the top during crystallization of the massif under fluid conditions (obviously, in the form of a complexes – for example, pair Au-Te or Me-As). Such metal-bearing fluid would be in equilibrium with the silicate magma. Heavy metals were transformed mainly into Cu-Fe sulphide globules when sulphide phase occurred in the residual silicate magma.

Summary

a) 60 PGM-grains were enriched into heavy concentrates from the sample 90-18 972 (800 g) by means of the new patented hydroseparator CNT HS-11.

b) The dominant PGE and Au minerals of the studied sample are vysotskite (46.7 vol. %), vasilite (20.8 vol. %), unnamed $(Au,Pd)_3Cu$ (10.8 vol. %), tetra-auricupride (4.2 vol. %), skaergaardite (4.8 vol. %), keithconnite (3.5 vol. %), arsenopalladinite (4.3 vol. %), palladoarsenide (2.2 vol. %), atokite (1 vol. %), unnamed Pd_3Ag_2S? (1 vol. %), (Pt,Fe,Pd,Cu) alloy (0.2 vol. %), $(Pd,Hg,Ag)_2S$ (0.3 vol. %), unnamed (Pd,Cu,Pb) alloy (0.3 vol. %).

c) The estimated bulk compositions of the sample (assays of whole rock in brackets) are (ppb): Pd 770 (745), Au 130 (114), Pt 3 (39). Pd is concentrated in vysotskite, vasilite and other Pd PGMs (740 ppb) less in gold minerals (30 ppb). Au is distributed between its own minerals (unnamed Au_3Cu and tetra-auricupride). Pt is concentrated partly in vysotskite and in own Pt alloys. The composition of Pt in the sample is close to the level of detection of the mineralogical analysis used.

d) 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

e) All above mentioned facts allow to suspect the replacement of heavy metals from bottom to the top during crystallization of the massif under fluid conditions (obviously, in the form of a complexes – for example, pair Au-Te or Me-As). Such metal-bearing fluid would be in equilibrium with the silicate magma. Heavy metals were transformed mainly into Cu-Fe sulphide globules when sulphide phase occurred in the residual silicate magma.

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TABLES

Table 1. Chemical composition and formulas of silicates and oxides of oxide-rich tholeiitic gabbros (sample 90-18 972)

Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Mineral	**pl**	**pl**	**cpx**	**cpx**	**opx**	**opx**	**ol**	**ol**	**ol**	**ilm**	**ilm**	**ilm**	**timt**	**timt**	**mt**	**tlc**	**tlc**	**fspn**	**fspn**
SiO_2	56.2	55.1	50.9	50.8	51.4	51.4	33.9	33.5	33.7	nd	nd	nd	nd	nd	nd	62.2	62.2	37.0	38.3
TiO_2	nd	nd	0.7	0.6	0.1	0.3	nd	nd	nd	51.3	51.5	51.5	13.6	13.2	nd	nd	nd	nd	nd
Al_2O_3	27.2	27.9	1.7	1.7	nd	nd	nd	nd	nd	nd	nd	nd	3.2	3.7	nd	nd	nd	nd	nd
V_2O_3	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.5	0.3	0.3	1.7	2	nd	nd	nd	5.7	5.9
Fe_2O_3	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.4	3.2	2.8	37.5	37.0	69.0	nd	nd	nd	nd
FeO	nd	nd	13.4	13.5	29.0	29.9	47.6	46.8	46.8	43.6	43.3	43.2	43.1	42.6	31.0	4.3	4.7	34.6	32.4
MnO	nd	nd	0.6	0.3	0.8	0.7	0.6	0.6	0.7	0.5	0.5	0.5	0.2	0.4	0.3	nd	nd	nd	nd
MgO	nd	nd	12.2	12.6	17.2	16.6	18.4	18.2	18.6	1.2	1.3	1.3	0.6	0.6	nd	28.4	28.2	2.9	2.5
CaO	8.8	9.9	19.9	19.4	1.2	0.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.0	2.2
Na_2O	6.6	5.9	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.3	2.1
K_2O	0.4	0.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.5	0.7
Total	99.2	99.2	99.4	98.9	99.7	99.7	100.5	99.1	99.8	99.5	100.1	99.6	99.9	99.5	100.3	94.9	95.1	84.0	84.1
Cations																			
Si	*2.55*	*2.5*	*1.94*	*1.94*	*1.99*	*2.01*	*1.00*	*1.00*	*1.00*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*4.02*	*4.01*	*3.39*	*3.47*
Ti	*nd*	*nd*	*0.02*	*0.02*	*0*	*0.01*	*nd*	*nd*	*nd*	*0.97*	*0.97*	*0.97*	*0.38*	*0.37*	*nd*	*nd*	*nd*	*nd*	*nd*
Al	*1.45*	*1.49*	*0.08*	*0.08*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*0.14*	*0.16*	*nd*	*nd*	*nd*	*nd*	*nd*
V	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*0.01*	*0.01*	*0.01*	*0.05*	*0.06*	*nd*	*nd*	*nd*	*nd*	*nd*
Fe^{3+}	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*0.05*	*0.06*	*0.06*	*1.05*	*1.04*	*2.00*	*nd*	*nd*	*nd*	*nd*
Fe^{2+}	*nd*	*nd*	*0.43*	*0.43*	*0.94*	*0.97*	*1.18*	*1.10*	*1.16*	*0.92*	*0.90*	*0.91*	*1.34*	*1.33*	*0.99*	*0.23*	*0.25*	*2.64*	*2.45*
Mn	*nd*	*nd*	*0.02*	*0.01*	*0.03*	*0.02*	*0.02*	*0.02*	*0.02*	*0.01*	*0.02*	*0.01*	*0.01*	*0.01*	*0.01*	*nd*	*nd*	*nd*	*nd*
Mg	*nd*	*nd*	*0.69*	*0.72*	*0.99*	*0.96*	*0.81*	*0.81*	*0.82*	*0.04*	*0.04*	*0.05*	*0.03*	*0.03*	*nd*	*2.73*	*2.73*	*0.40*	*0.34*
Ca	*0.43*	*0.48*	*0.81*	*0.79*	*0.05*	*0.03*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*0.19*	*0.22*
Na	*0.58*	*0.52*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*0.22*	*0.38*
K	*0.02*	*0.02*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*nd*	*0.07*	*0.08*
# of O	*8*	*8*	*6*	*6*	*6*	*6*	*4*	*4*	*4*	*3*	*3*	*3*	*4*	*4*	*4*	*11*	*11*	*11*	*11*

Table 2. Chemical composition and formulas of base metal sulphides in PGM-bearing globules of the heavy concentrates (sample 90-18 972)

				weight percent				*atomic proportions*			
An	**Grain**	**Association**	**Mineral**	**Cu**	**Fe**	**S**	**Total**	***Cu***	***Fe***	***S***	***Total***
1	40 gr b	ch	ch	77.7	1.0	19.9	98.6	*1.97*	*0.03*	*1.00*	*3*
2	40 gr 1a	bn	bn	63.3	11.5	25.3	100.1	*5.00*	*1.03*	*3.97*	*10*
3	40 gr2c	bn	bn	63.1	11.7	25.5	100.3	*4.97*	*1.05*	*3.99*	*10*
4	40 gr2g	bn	bn	63.2	11.5	25.5	100.2	*4.98*	*1.03*	*3.99*	*10*
5	40 gr 2h	ch+ilm	ch	78.7	1.8	20.1	100.6	*1.96*	*0.05*	*0.99*	*3*
6	40 gr11b	bn	bn	53.4	11.4	25.5	100.3	*5.00*	*1.02*	*3.98*	*10*
7	40 gr17	vys+bn	bn	63.0	11.4	25.4	99.8	*4.99*	*1.03*	*3.99*	*10*
8	40 gr19	vys+bn	bn	63.1	11.3	25.5	99.9	*4.99*	*1.02*	*4.00*	*10*
9	40 gr25	AuCu+kth+vys+ch	ch	79.2	0.5	20.2	99.9	*1.98*	*0.01*	*1.00*	*3*
10	125 gr15	vs+bn+ch	ch	78.9	0.5	20.1	99.5	*1.98*	*0.02*	*1.00*	*3*
11	125 gr10b	bn	bn	62.6	11.2	25.4	99.2	*4.98*	*1.02*	*4.01*	*10*
12	125 gr9a	ch+bn	ch	78.6	0.8	20.1	99.5	*1.98*	*0.02*	*1.00*	*3*
13	125 gr9a	ch+bn	bn	62.6	11.6	25.5	99.7	*4.95*	*1.04*	*4.00*	*10*
14	125 gr9b	bn+dg	dg	76.0	1.8	21.7	99.5	*8.79*	*0.24*	*4.97*	*14*
15	125 gr9b	bn+dg	bn	63.4	11.2	25.9	100.5	*4.97*	*1.00*	*4.03*	*10*
16	125 gr9c	ch+bn	ch	78.0	1.6	20.2	99.8	*1.95*	*0.05*	*1.00*	*3*
17	125 gr9c	ch+bn	bn	63.1	11.4	25.5	100.0	*4.98*	*1.03*	*3.99*	*10*
18	125 gr9d	ch+bn	ch	78.9	1.2	20.6	100.7	*1.95*	*0.03*	*1.01*	*3*
19	125 gr9d	ch+bn	bn	62.5	11.0	25.7	99.2	*4.96*	*0.99*	*4.04*	*10*
20	125 gr9e	ch+bn	ch	77.9	1.4	20.2	99.5	*1.96*	*0.04*	*1.00*	*3*
21	125 gr9e	ch+bn	bn	63.2	10.7	25.2	99.1	*5.04*	*0.97*	*3.99*	*10*

Table 3. PGE and Au minerals in heavy concentrates of the sample 90-18 972

N	Mineral	General formula	Number of grains	Grain size, μm			Vol. %
				min	max	average	
1	Vysotskite	(Pd,Cu,Ni,Fe)S	30	1	23	10	46.7
2	Vasilite	Pd12(Cu,Fe)4S7	11	4	20	12	20.8
3	Unnamed	(Au,Pd)3(Cu,Fe)	4	2	22	14	10.8
4	Tetra-auricupride	(Au,Pd)(Cu,Fe)	2	3	18	12	4.2
5	Skaergaardite	(Pd,Au)(Cu,Fe,Zn)	2	2	20	11	4.8
6	Keithconnite	(Pd,Cu,Fe)3(Te,As,Sn)	9	2	7	5	3.5
7	Arsenopalladinite	(Pd,Cu,Fe)8As3	5	1	18	7	4.3
8	Palladoarsenide	(Pd,Cu,Fe)2As	1			14	2.2
9	Atokite	(Pd,Cu,Fe)2Sn	2	2	9	5	1
10	Alloy	(Pt,Fe,Pd,Cu)	1			5	0.2
11	Unnamed	Pd3Ag2S?	3	2	7	5	1
12	Unnamed	(Pd,Hg,Ag)2+xS	1			6	0.3
13	Alloy	(Pd,Cu,Pb)	1			5	0.2
	Total						100.0

Table 4. Size of precious metal mineral grains (sample 90-18 972)

#	Grain	Association	Type	Mineral	Area, μm^2	ECD, µm	Note - grains:S
1	125-10	(Pd,Ag)2S-bn-ch	bms	(Pd,Ag)2S	41	7.2	
2	125-11	vys-bn-ch	bms	vys	44	7.5	
3	125-12	(Ag,Cu)	L	(Ag,Cu)	888	33.6	
4	125-14	(Au,Cu,Ag)-kth-bn-ch	bms	(Au,Cu,Ag)	33	6.5	3 grains: 15, 7, 11
5	125-14	(Au,Cu,Ag)-kth-bn-ch	bms	kth	32	6.4	2 grains: 28, 4
6	125-14	(Au,Cu,Ag)-kth-bn-ch	bms	total	65	9.1	
7	125-15	vs-bn-ch	bms	vs	161	14.3	
8	125-1	vys-ch-bn	bms	vys	20	5	
9	125-2	vs-(Pd,Ag)S?-bn-ch	bms	vs	20	5	
10	125-2	vs-(Pd,Ag)S?-bn-ch	bms	(Pd,Ag)S?	13	4.1	
11	125-2	vs-(Pd,Ag)S?-bn-ch	bms	total	33	6.5	
12	125-3	vs-bn-ch	bms	vs	10	3.6	
13	125-4	vys-(Pd,Hg,Ag)2S-bn	bms	vys	280	18.9	
14	125-5	Au3Cu-kth-ch-bn-chl	sag	Au3Cu	78	10	4 grains: 39, 21, 8, 4
15	125-5	Au3Cu-kth-ch-bn-chl	sag	kth	14	4.2	2 grains: 8, 6
16	125-5	Au3Cu-kth-ch-bn-chl	sag	total	92	10.8	
17	125-6	vys-bn-ch-ilm	sag	vys	2	1.6	
18	125-7	vs-bn-ch-srp	sag	vs	79	10	
19	125-8	vys-ch-bn-srp-ct	sag	vys	205	16.2	2 grains: 192, 13
20	125-9	apd-bn-ch	bms	apd	9	3.4	
21	125d	vys-ch-bn	bms	vys	2	1.6	
22	40-10	vys-ch	bms-L	vys	197	15.8	
23	40-11	at-bn	bms	at	60	8.7	5 grains: 26, 16, 9, 6, 3
24	40-12	(Ag,Cu)	L	(Ag,Cu)	165	14.5	
25	40-13	vys-ch	bms	vys	176	15	4 grains: 88, 44, 28, 16
26	40-14	(Pt,Fe,Cu,Pd)-bn-ch	bms	(Pt,Fe)	16	4.5	
27	40-15	vs-sk?	Lp	sk	4	2.3	
28	40-15	vs-sk?	Lp	vs	314	20	
29	40-15	vs-sk?	Lp	total	318	20.1	
30	40-16	(Ag,Cu)	L	(Ag,Cu)	144	13.5	
31	40-17	vys-bn	bms	vys	148	13.7	
32	40-18	vs-bn	bms-L	vs	120	12.4	
33	40-19	vys-bn	bms	vys	62	8.9	
34	40-1	vys-bn-ch	bms-L	vys	396	22.5	
35	40-20	vys-bn	bms	vys	11	3.7	2 grains: 7, 4
36	40-21	vs-kth-bn	bms	kth	23	5.4	6 grains: 13, 2, 2, 2, 2, 2
37	40-21	vs-kth-bn	bms	vs	257	18.1	
38	40-21	vs-kth-bn	bms	total	280	18.9	
39	40-22	(Ag,Pd)S?-bn-ch	bms	(Ag,Pd)S?	10	3.6	3 grains: 6, 2, 2
40	40-23	(Ag,Cu)	L	(Ag,Cu)	912	34.1	
41	40-24	vs-apd-bn	bms-L	apd	7	3	4 grains: 4, 1, 1, 1
42	40-24	vs-apd-bn	bms-L	vs	172	14.8	
43	40-24	vs-apd-bn	bms-L	total	179	15.1	
44	40-25	AuCu-vys-kth-ch	bms	AuCu	250	17.8	
45	40-25	AuCu-vys-kth-ch	bms	kth	21	5.2	3 grains: 13, 5, 3
46	40-25	AuCu-vys-kth-ch	bms	vys	137	13.2	
47	40-25	AuCu-vys-kth-ch	bms	total	408	22.8	
48	40-26	sk-bn-ch	bms	sk	316	20.1	
49	40-27	vys-bn-ch	bms	vys	6	2.8	3 grains: 4, 1, 1

Table 4 continued

#	Grain	Association	Type	Mineral	Area, mm2	ECD, mm	Note - grains:S
50	40-28	vs-bn-ch	bms	vs	51	8.1	
51	40-29	Au3Cu-cpx	ag	Au3Cu	124	12.6	
52	40-2	vys-ch-bn	bms	vys	123	12.5	
53	49-30	Au3Cu-kth	Lp	Au3Cu	384	22.1	
54	49-30	Au3Cu-kth	Lp	kth	8	3.2	
55	49-30	Au3Cu-kth	Lp	total	392	22.3	
56	40-31	vys-bn	bms	vys	250	17.8	
57	40-3	vys-bn-ch	bms	vys	85	10.4	
58	40-4	Au3Cu	L	Au3Cu	134	13.1	
59	40-5	vys-ch-bn	bms	vys	11	3.7	
60	40-6	apd	L	apd	245	17.7	
61	40-7	vys-cpx	ag	vys	22	5.3	
62	40-8	at-apd-ch-bn	bms	apd	10	3.6	
63	40-8	at-apd-ch-bn	bms	at	5	2.5	
64	40-8	at-apd-ch-bn	bms	total	15	4.4	
65	40-9	vys-bn-ch	bms	vys	5	2.5	
66	63-1	vys-bn-ch	bms	vys	184	15.3	21 grains: 20, 21, 10, <2
67	63-2	vys-bn-ch-ep	sag	vys	153	14	
68	63-3	vys-ch-bn	bms	vys	115	12.1	
69	63-4	apd-ch-bn	bms	apd	18	4.8	
70	63-5	kth-ch-bn	bms	kth	42	7.3	
71	63-6	vys-bn-ch	bms	vys	89	10.6	
72	63-7	vys-bn-ch	bms	vys	317	20.1	
73	80-10	vys-ch-bn	bms	vys	14	4.2	
74	80-11	vys-bn-ch	bms	vys	47	7.7	
75	80-12	vys-ch-bn	bms	vys	24	5.5	
76	80-1	kth-vs-ch-bn	bms	kth	28	6	
77	80-1	kth-vs-ch-bn	bms	vs	38	7	
78	80-1	kth-vs-ch-bn	bms	total	66	9.2	
79	80-2	pars-bn-chl	sag	pars	149	13.8	
80	80-3	vys-bn-ch	bms	vys	2	1.6	
81	80-4	vys-bn-ch-chl	sag	vys	16	4.5	
82	80-8	kth-bn--ch-trm	sag	kth	32	6.4	
83	80-9	vs-kth-ch-bn-chl	sag	vs	187	15.4	
84	80-9	vs-kth-ch-bn-chl	sag	kth	37	6.9	7 grains: 13, 5, 7, 3, 3, 3, 3
85	80-9	vs-kth-ch-bn-chl	sag	total	224	16.9	

Table 5	**Associations of PGE and Au mineral grains in heavy concentrates of the sample 90-18, 972**	
Association	**PGM-grains, number**	**PGM-grains, vol. %**
bms	41	54
bms-L	4	13.3
L	2	5.7
L^+	2	10.6
sag	9	14.2
ag	2	2.2

Table 6. Chemical composition and formulas of the vysotskite in PGM-grains of the heavy concentrates (sample 90-18 972)

			Analysis							Atomic proportions					
An	**Grain**	**Association**	**Pd**	**Pt**	**Cu**	**Fe**	**Ni**	**S**	**Total**	***Pd***	***Pt***	***Cu***	***Fe***	***Ni***	***S***
1	40 gr1	vys+bn+ch	69.7	0.0	5.3	0.5	0.6	24.3	100.4	*0.86*	*0.00*	*0.11*	*0.01*	*0.01*	*1.00*
2	40 gr2	vys+ch+bn	72.8	0.0	2.2	0.5	0.0	23.5	99.0	*0.94*	*0.00*	*0.05*	*0.01*	*0.00*	*1.00*
3	40 gr3	vys+bn+ch	73.5	0.0	1.9	0.8	0.0	23.8	100.0	*0.94*	*0.00*	*0.04*	*0.02*	*0.00*	*1.00*
4	40 gr10	vys+ch	75.3	0.0	0.0	0.5	0.0	23.2	99.0	*0.98*	*0.00*	*0.00*	*0.01*	*0.00*	*1.01*
5	40 gr13	vys+ch	74.5	0.0	1.5	0.7	0.0	23.3	100.0	*0.96*	*0.00*	*0.03*	*0.02*	*0.00*	*0.99*
6	40 gr17	vys+bn	75.9	0.0	0.6	0.5	0.0	23.3	100.3	*0.98*	*0.00*	*0.01*	*0.01*	*0.00*	*1.00*
7	40 gr19	vys+bn	68.5	0.0	4.0	1.3	1.5	24.3	99.6	*0.85*	*0.00*	*0.08*	*0.03*	*0.03*	*1.00*
8	40 gr25	AuCu+kth+vys+ch	75.6	0.0	0.6	0.0	0.0	23.2	99.4	*0.98*	*0.00*	*0.01*	*0.01*	*0.00*	*1.00*
9	40 gr32	vys+bn	74.1	0.0	0.0	0.5	1.4	23.2	99.2	*0.96*	*0.00*	*0.00*	*0.01*	*0.03*	*1.00*
10	63 gr1	vys+bn+ch	73.4	0.0	2.6	0.5	0.0	23.7	100.2	*0.93*	*0.00*	*0.06*	*0.01*	*0.00*	*1.00*
11	63 gr2	vys+bn+ch+ep	66.0	1.2	2.6	0.4	4.5	24.3	99.0	*0.82*	*0.01*	*0.05*	*0.01*	*0.10*	*1.00*
12	63 gr3	vys+bn+ch	73.4	0.0	1.6	0.6	0.0	23.5	99.1	*0.95*	*0.00*	*0.03*	*0.01*	*0.00*	*1.00*
13	63 gr6	vys+bn+ch	72.8	0.0	2.0	0.7	1.1	24.0	100.6	*0.91*	*0.00*	*0.04*	*0.02*	*0.03*	*1.00*
14	63 gr7	vys+ch+bn	70.2	1.3	1.3	0.4	3.1	23.8	100.1	*0.89*	*0.01*	*0.03*	*0.01*	*0.07*	*1.00*
15	80 gr10	vys+ch+bn+chl	72.6	0.0	2.3	0.8	0.0	23.5	99.2	*0.93*	*0.00*	*0.05*	*0.02*	*0.00*	*1.00*
16	125 gr4	vys+(Pd,Hg,Ag)2S+bn+ch+chl	74.8	0.0	1.8	0.4	0.0	23.5	100.5	*0.96*	*0.00*	*0.04*	*0.01*	*0.00*	*1.00*
17	125 gr8	vys+bn+ch+ct+srp	74.3	0.0	2.4	0.6	0.0	23.6	100.9	*0.94*	*0.00*	*0.05*	*0.01*	*0.00*	*0.99*
18		Average vysotskite	72.8	0.1	1.9	0.6	0.7	23.6	99.7	*0.93*	*0.00*	*0.04*	*0.01*	*0.02*	*1.00*
		max		1.3	5.3	1.3	4.5								

Table 7. Chemical composition and formulas of the vasilite, unnamed $(Pd,Hg,Ag)_2S$ unnamed Pd3Ag2S in PGM-grains of the heavy concentrates (sample 90-18 972)

			Analysis							Atomic proportions					
An.	**Grain**	**Association**	**Pd**	**Cu**	**Fe**	**Ag**	**Hg**	**S**	**Total**	***Pd***	***Cu***	***Fe***	***Ag***	***Hg***	***S***
1	40 gr15	vs+(Pd,Au,Cu)	71.9	14.6	0.8	nd	nd	12.7	100.0	*11.81*	*4.02*	*0.25*	*nd*	*nd*	*6.92*
2	40 gr18	vs+bn	72.0	13.7	1.0	nd	nd	12.8	99.5	*11.90*	*3.78*	*0.32*	*nd*	*nd*	*7.00*
3	40 gr21	vs+kth+bn	71.5	14.6	0.6	nd	nd	12.8	99.5	*11.77*	*4.04*	*0.19*	*nd*	*nd*	*7.01*
4	40 gr24	vs+apd+bn	72.3	13.5	0.6	nd	nd	12.6	99.1	*12.05*	*3.78*	*0.19*	*nd*	*nd*	*6.98*
5	40 gr28	vs+bn+ch	72.3	12.8	1.2	nd	nd	12.7	99.0	*12.04*	*3.57*	*0.38*	*nd*	*nd*	*7.03*
6	80 gr1	vs+kth+chl	72.3	14.4	0.5	nd	nd	12.8	100.0	*11.89*	*3.97*	*0.16*	*nd*	*nd*	*6.99*
7	80 gr9	vs+kth+ch+bn+ilm	72.4	15.0	0.6	nd	nd	12.9	100.9	*11.77*	*4.08*	*0.19*	*nd*	*nd*	*6.96*
8	125 gr7	vs+bn+ch+ct+srp	72.0	14.7	1.0	nd	nd	13.0	100.7	*11.69*	*4.00*	*0.31*	*nd*	*nd*	*7.00*
9		avr vs	72.1	14.2	0.8	nd	nd	12.8	99.9	*11.86*	*3.90*	*0.25*	*nd*	*nd*	*6.99*
10	125 gr4	vys+(Pd,Hg,Ag)2S+bn+ch+chl	59.9	1.6	0.8	7.3	17.1	12.1	98.8	*1.49*	*0.07*	*0.04*	*0.18*	*0.23*	*1.00*
11	125 gr10	Pd_3Ag_2S+bn+ch	55.1	2.3	1.3	36.1	nd	5.1	100.0	*2.90*	*0.20*	*0.13*	*1.87*	*nd*	*0.90*

Table 8. Chemical composition and formulas of skaergaardite, arsenopalladinite, palladoarsenide, keithconnite, atokite and unnamed (Pd,Cu,Sn) alloy- in PGM-grains of the heavy concentrates (sample 90-18, 972)

			Analysis										Atomic proportions									
An	**Association**	**Mineral**	**Pd**	**Au**	**Cu**	**Fe**	**Zn**	**Sn**	**Te**	**Pb**	**As**	**Total**	***Pd***	***Au***	***Cu***	***Fe***	***Zn***	***Sn***	***Te***	***Pb***	***As***	***Total***
1	sk+bn+ch	sk	62.3	0.0	31.5	3.4	1.9	0.0	0.0	0.0	0.0	99.1	*1.00*	*0.0*	*0.9*	*0.10*	*0.05*	*0.0*	*0.0*	*0.0*	*0.0*	*2*
2	apd	apd	74.1	0.0	3.1	0.6	nd	0.0	0.0	0.0	21.4	99.3	*7.35*	*0.00*	*0.52*	*0.11*	*nd*	*0.00*	*0.00*	*0.00*	*3.02*	*11*
3	pars+bn+chl	pars	71.8	0.0	1.2	0.4	nd	0.0	0.0	0.0	26.0	99.4	*1.93*	*0.00*	*0.05*	*0.02*	*nd*	*0.00*	*0.00*	*0.00*	*0.99*	*3*
4	vs+kth+bn	kth	75.5	0.0	3.1	0.8	nd	1.8	12.2	0.0	6.0	99.4	*2.94*	*0.00*	*0.2*	*0.06*	*nd*	*0.06*	*0.40*	*0.00*	*0.33*	*4*
5	AuCu+kth+vys+ch	kth	70.9	3.2	2.0	0.0	nd	5.3	12.9	0.0	4.7	99.0	*2.89*	*0.07*	*0.14*	*0.00*	*nd*	*0.19*	*0.44*	*0.00*	*0.27*	*4*
6	kth+Au_3Cu	kth	70.2	0.0	0.0	1.6	nd	7.0	16.6	0.0	3.8	99.3	*2.84*	*0.00*	*0.00*	*0.13*	*nd*	*0.25*	*0.56*	*0.00*	*0.22*	*4*
7	kth+bn+ch	kth	70.2	0.0	2.5	0.8	nd	0.0	24.7	0.0	1.6	99.8	*2.84*	*0.00*	*0.17*	*0.06*	*nd*	*0.00*	*0.83*	*0.00*	*0.09*	*4*
8	vs+kth+ch+bn+ilm	kth	69.3	0.0	2.7	0.7	nd	0.0	27.4	0.0	0.0	100.1	*2.83*	*0.00*	*0.18*	*0.05*	*nd*	*0.00*	*0.93*	*0.00*	*0.00*	*4*
9	Au_3Cu+kth+bn+ch+chl	kth	70.9	0.0	4.6	0.6	nd	2.4	13.7	0.0	7.0	99.2	*2.75*	*0.00*	*0.3*	*0.04*	*nd*	*0.08*	*0.44*	*0.00*	*0.39*	*4*
10	vs+kth+(Au,Cu,,Ag)+bn+ch+hb	kth	68.9	0.0	2.3	0.7	nd	0.0	27.5	0.0	0.0	99.4	*2.84*	*0.00*	*0.16*	*0.06*	*nd*	*0.00*	*0.95*	*0.00*	*0.00*	*4*
11	at+bn	at	72.4	1.2	1.8	0.8	nd	23.6	0.0	0.0	0.0	99.8	*2.93*	*0.03*	*0.12*	*0.06*	*nd*	*0.86*	*0.00*	*0.00*	*0.00*	*4*
12	(Pd,Cu,Pb)	(Pd,Cu,Pb)	78.0	0.0	3.8	0.7	nd	0.0	0.0	17.3	0.0	99.8	*0.82*	*0.00*	*0.07*	*0.01*	*nd*	*0.00*	*0.00*	*0.09*	*0.00*	*1*

Table 9. Chemical composition and formulas of tetra-auricupride and unnamed Au_3Cu, (Au,Cu,Ag) alloy, (Pd,Au,Cu) alloy, (Pt,Fe,Pd,Cu) alloy and (Ag,Cu) alloy in grains of the heavy concentrates (sample 90-18 972)

							Analysis							***Atomic proportions***			
An	**Grain**	**Association**	**Mineral**	**Pd**	**Pt**	**Au**	**Ag**	**Cu**	**Fe**	**Total**	***Pd***	***Pt***	***Au***	***Ag***	***Cu***	***Fe***	***Total***
1	40 gr25	AuCu+kth+vys+ch	AuCu	19.2	0.0	53.2	nd	25.8	0.8	99.0	*0.41*	*0.09*	*0.62*	nd	*0.93*	*0.03*	*2*
							nd							nd			
2	40 gr4	Au_3Cu	Au_3Cu	8.3	0.0	79.7	nd	10.8	0.9	99.7	*0.47*	*0.00*	*2.42*	nd	*1.02*	*0.10*	*4*
3	40 gr29	Au_3Cu+cpx	Au_3Cu	9.1	0.0	78.8	nd	10.3	1.1	99.3	*0.51*	*0.00*	*2.40*	nd	*0.97*	*0.12*	*4*
4	40 gr31	Au_3Cu+kth	Au_3Cu	13.4	0.0	78.9	nd	8.1	0.4	100.8	*0.76*	*0.00*	*2.43*	nd	*0.77*	*0.04*	*4*
5	125 gr5	Au_3Cu+kth+bn+ch+chl	Au_3Cu	12.1	0.0	77.8	nd	9.8	0.5	100.2	*0.68*	*0.00*	*2.35*	nd	*0.92*	*0.06*	*4*
6		avr	Au_3Cu	10.7	nd	78.8		9.8	0.7	100.0	*0.61*	*0.00*	*2.40*	nd	*0.92*	*0.08*	*4*
7	125 gr14	vs+kth+(Au,Cu,,Ag)+bn+ch+hb	(Au,Cu,Ag)	12.7	nd	57.7	17.7	10.6	1.3	100.0	*0.16*	*0.00*	*0.38*	*0.21*	*0.22*	*0.03*	*1*
8	40 gr15	vs+(Pd,Au,Cu)	(Pd,Cu,Au)	64.6	0.0	26.2	nd	7.4	1.7	100.0	*0.68*	*0.00*	*0.15*	nd	*0.13*	*0.03*	*1*
														nd			
9	40 gr14	(Pt,Fe,Pd)+ch+bn	(Pt,Fe,Pd)	17.6	64.6	1.5		4.0	11.3	99.0	*0.21*	*0.43*	*0.01*	nd	*0.08*	*0.26*	*1*
10	40 gr12	(Ag,Cu)	(Ag,Cu)	nd	nd	nd	90.9	6.5	1.6	99.0	nd	nd	nd	*0.87*	*0.10*	*0.03*	*1*
11	40 gr16	(Ag,Cu)	(Ag,Cu)	nd	nd	nd	92.6	6.1	0.8	99.5	nd	nd	nd	*0.89*	*0.10*	*0.01*	*1*
12	40 gr23	(Ag,Cu)	(Ag,Cu)	nd	nd	nd	93.1	5.3	0.6	99.0	nd	nd	nd	*0.90*	*0.09*	*0.01*	*1*
13	125 gr12	(Ag,Cu)	(Ag,Cu)	nd	nd	nd	92.2	6.4	0.4	99.0	nd	nd	nd	*0.89*	*0.10*	*0.01*	*1*
14		avr	(Ag,Cu)	nd	nd	nd	92.2	6.1	0.9	99.1	nd	nd	nd	*0.89*	*0.10*	*0.02*	*1*

Plate 1

Relationships of rock-forming minerals, Fe-Ti oxides, sulphides and PGM in the oxide-rich tholeitic gabbros of the sample 90-18, 972 (1-4); polished section, SEM-image (BIE). Pl –plagioclase, pyr (exs) – pyroxene exsolution texture,: cpx – clinopyroxene, opx – orthopyroxene, ilm – ilmenite, timt – titaniferous magnetite, ol – olivine, mt – magnetite, tlc - talc, bn – bornite, (Pd,Cu,Pb) – Pd-Cu-Pb alloy; 4 is part of the 3.

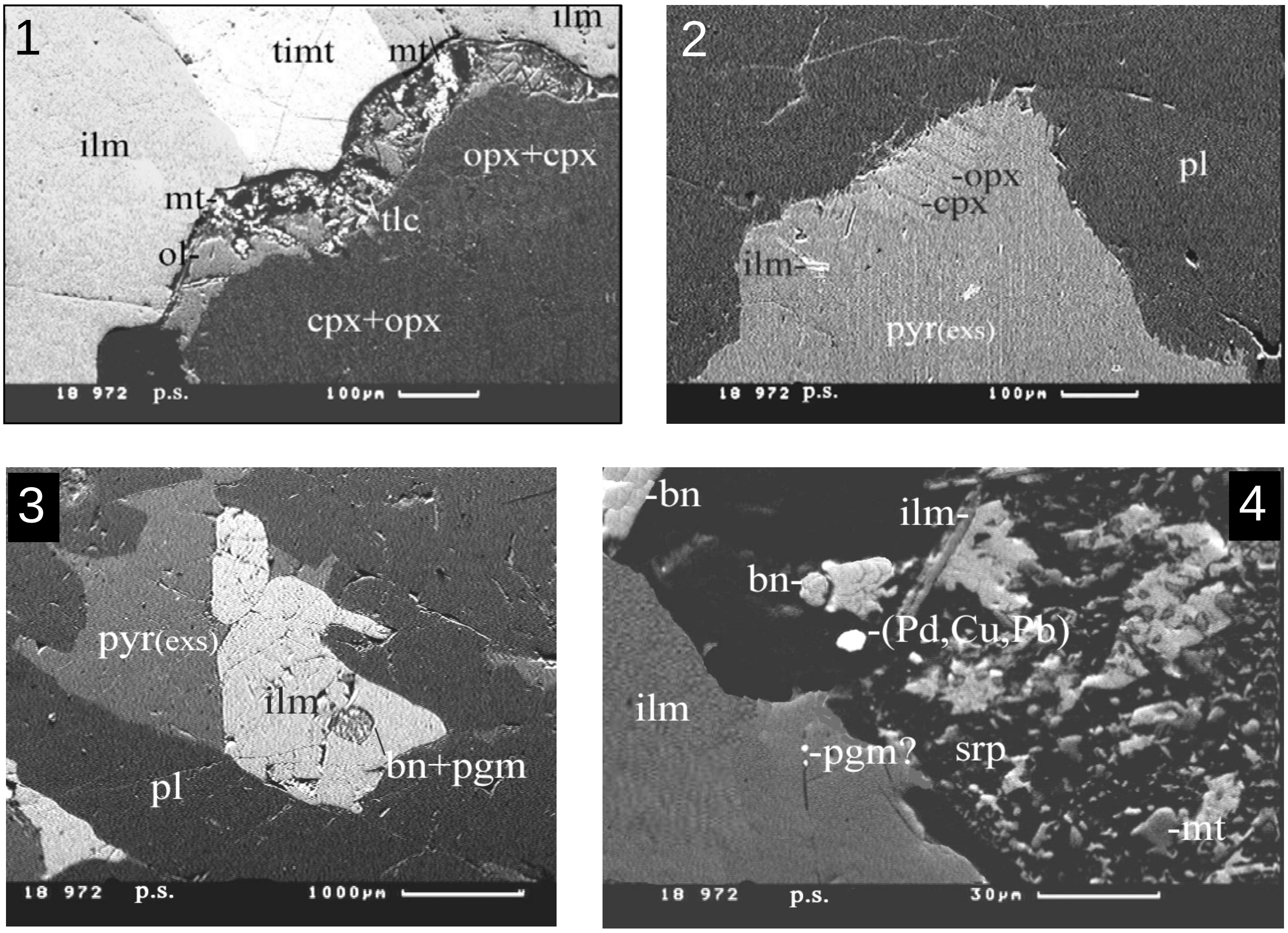

1
ilm
timt
mt
ilm
opx+cpx
mt-
tlc
ol-
cpx+opx
18 972 p.s.
100µm
2
-opx
-cpx
pl
ilm-
pyr(exs)
18 972 p.s.
100µm
3
pyr(exs)
ilm
bn+pgm
pl
18 972 p.s.
1000µm
4
-bn
ilm-
bn-
-(Pd,Cu,Pb)
ilm
:-pgm?
srp
-mt
18 972 p.s.
30µm

Plate 2

Polished sections of heavy concentrates (1-4: 1, 2 – fraction 80-125 µm; 3 – fraction 63-80 µm; 4 – fraction 40-63 µm), sample 90-18 972, SEM-images (BIE); ilm – ilmenite, vys – vysotskite, bn – bornite, ch – chalcosine group minerals, cpx – clinopyroxenes.

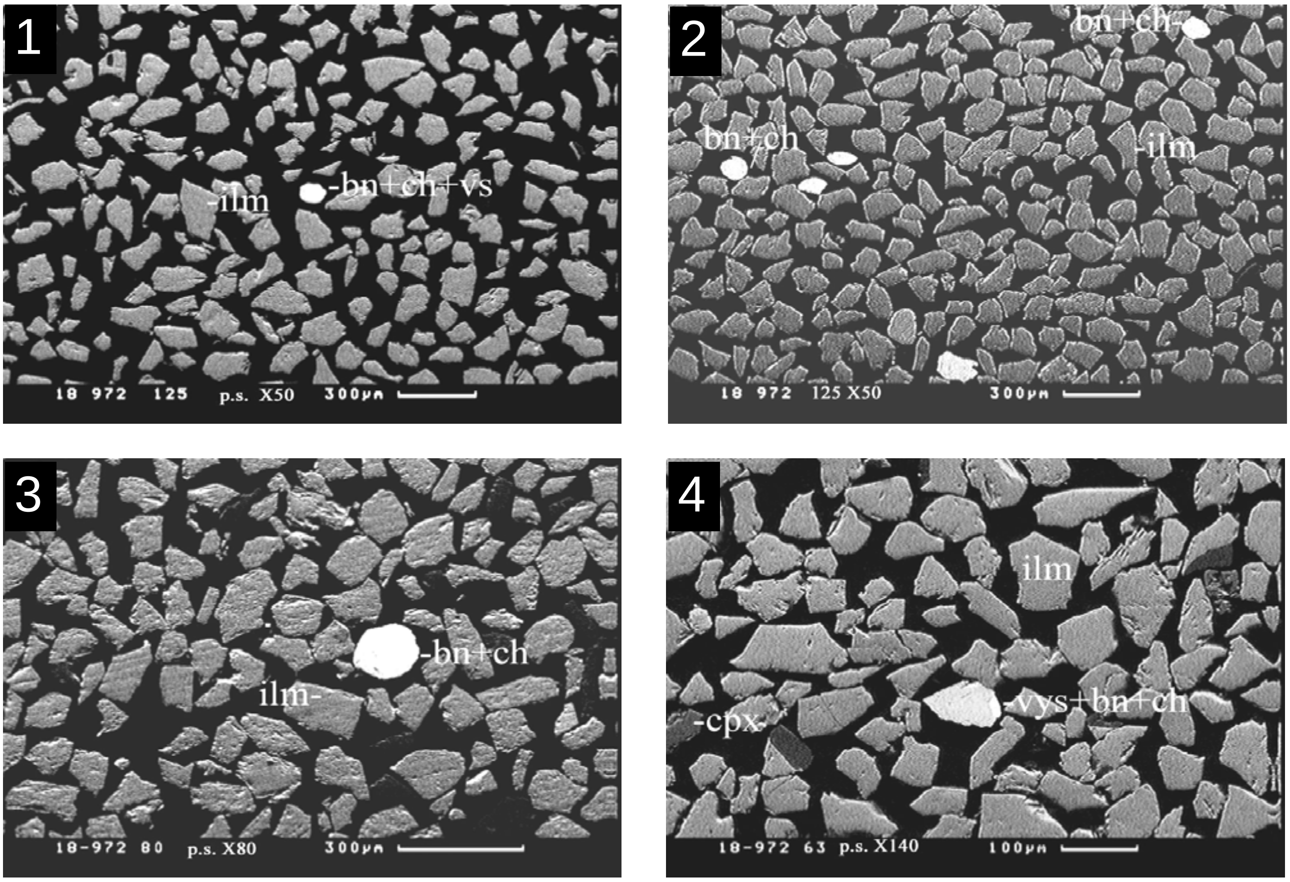

1
-ilm
-bn+ch+vs
18 972 125 p.s. X50 300μm
2
bn+ch-
bn+ch
-ilm
18 972 125 X50 300μm
3
-bn+ch
ilm-
18-972 80 p.s. X80 300μm
4
ilm
-vys+bn+ch
-cpx-
18-972 63 p.s. X140 100μm

Plate 3

Baddeleyite grains (for age dating), extracted in the heavy concentrate of the sample 90-18, 972 (1-5); polished section, SEM-image (BIE).

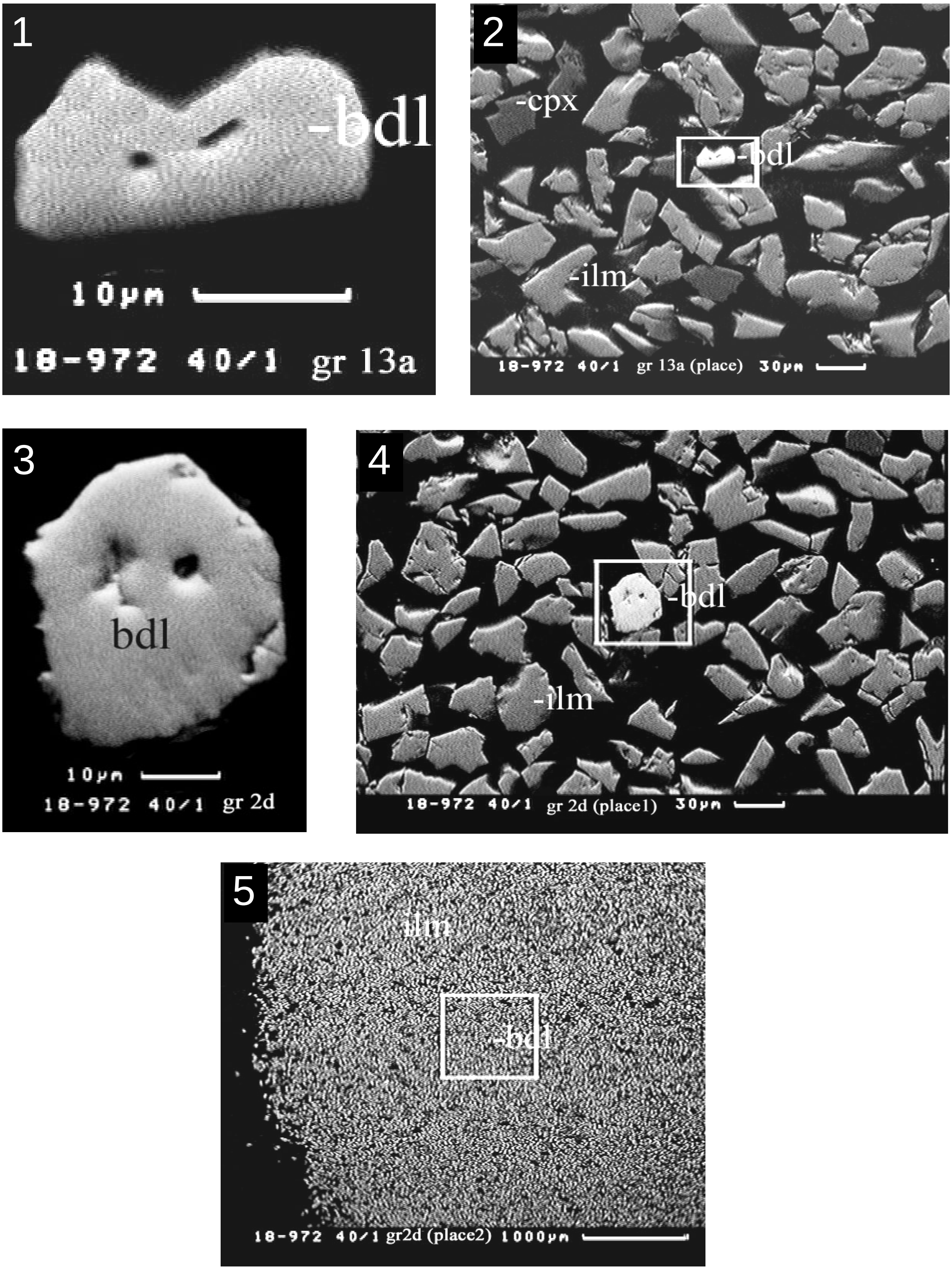
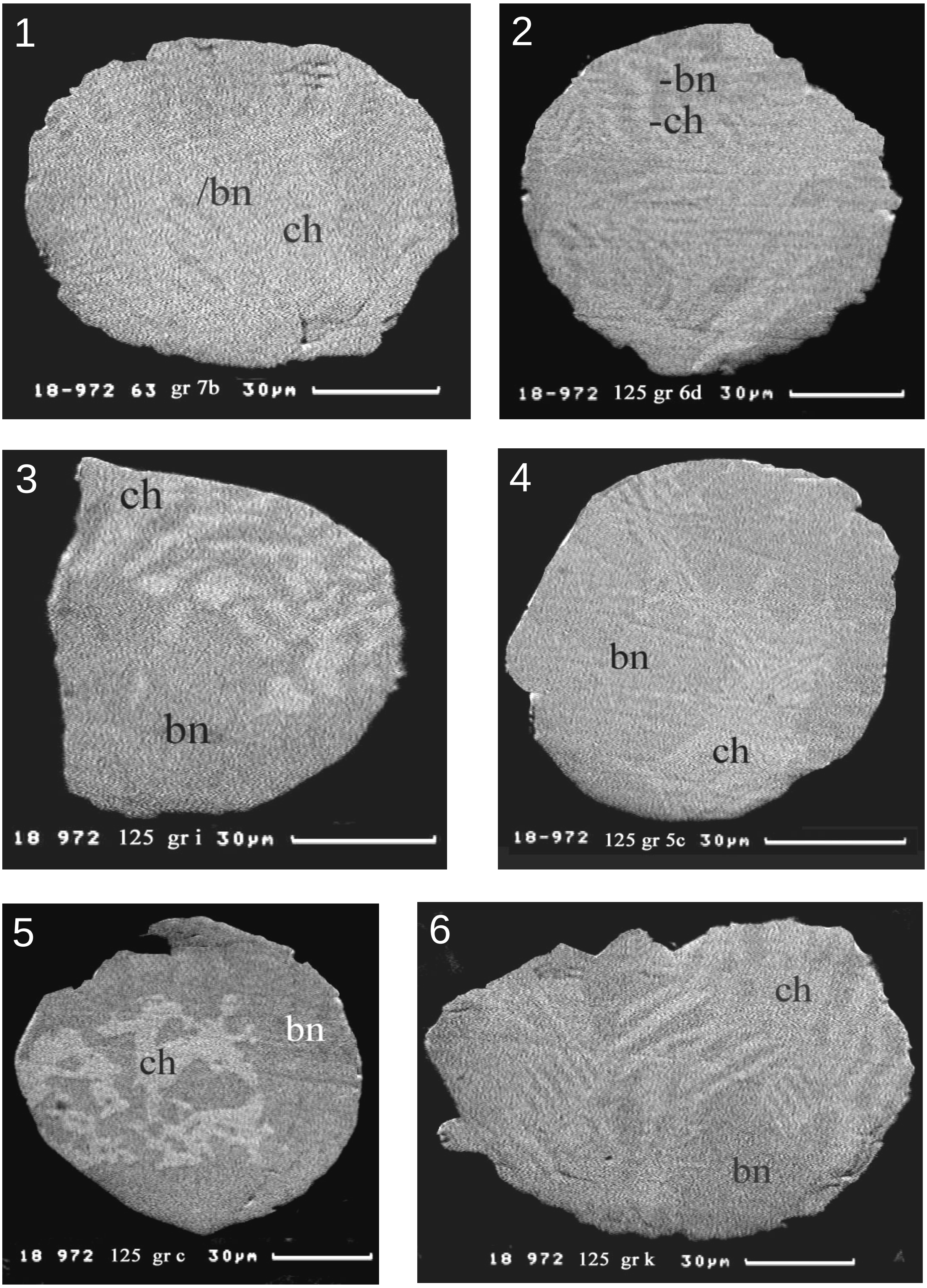
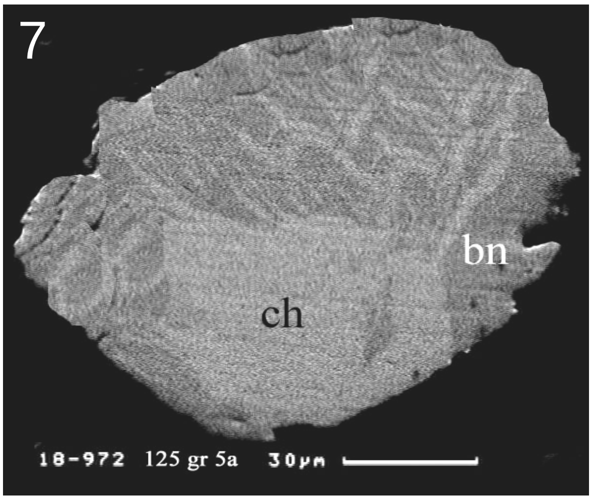
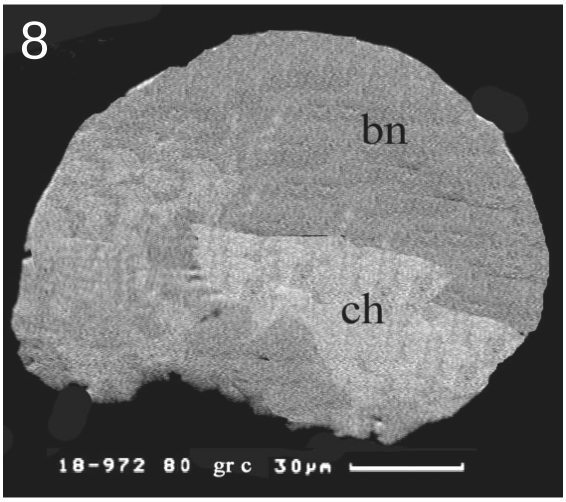

1
-bdl
10μm
18-972 40/1 gr 13a
2
-cpx
-bdl
-ilm
18-972 40/1 gr 13a (place) 30μm
3
bdl
10μm
18-972 40/1 gr 2d
4
-bdl
-ilm
18-972 40/1 gr 2d (place1) 30μm
5
ilm
-bdl
18-972 40/1 gr2d (place2) 1000μm

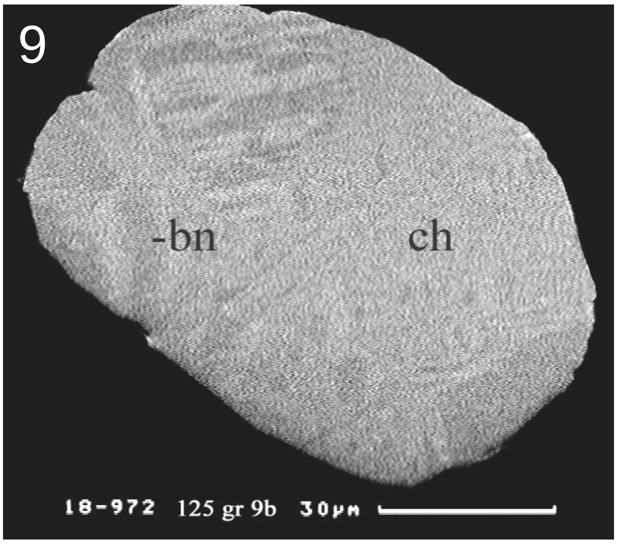
Plate 4

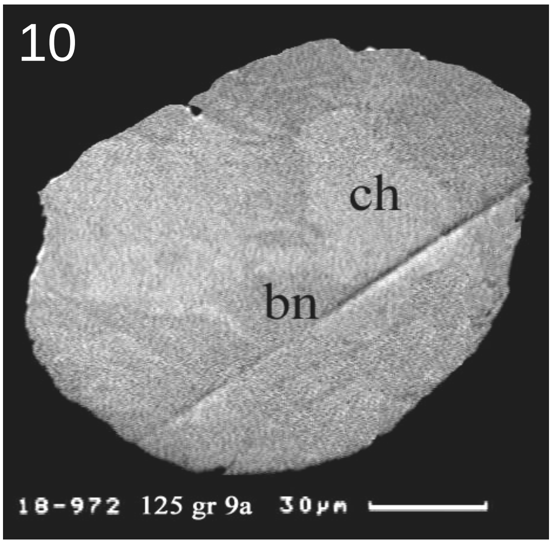
Sulphide mineralisation globules and irragular form grains of oxide-rich tholeitic gabbros, the sample 90-18 972 (1-37), polished section of grains, extracted in the heavy concentrate, SEM-image (BIE); bn – bornite, ch – chalcosine, ilm – ilmenite, chl – chlorite, tlc-talc, ct – calcite.

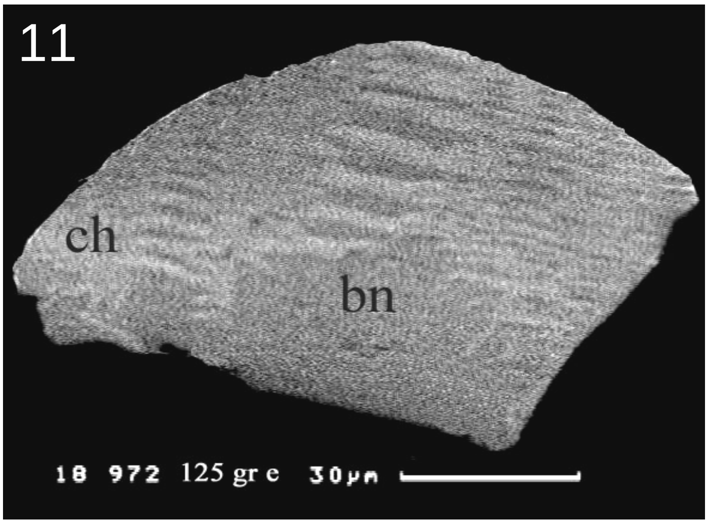

1
/bn
ch
18-972 63 gr 7b 30μm
2
-bn
-ch
18-972 125 gr 6d 30μm
3
ch
bn
18 972 125 gr i 30μm
4
bn
ch
18-972 125 gr 5c 30μm
5
bn
ch
18 972 125 gr c 30μm
6
ch
bn
18 972 125 gr k 30μm

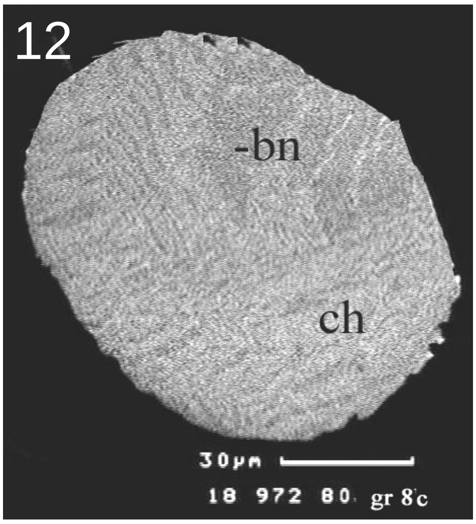

7
bn
ch
18-972 125 gr 5a 30μm

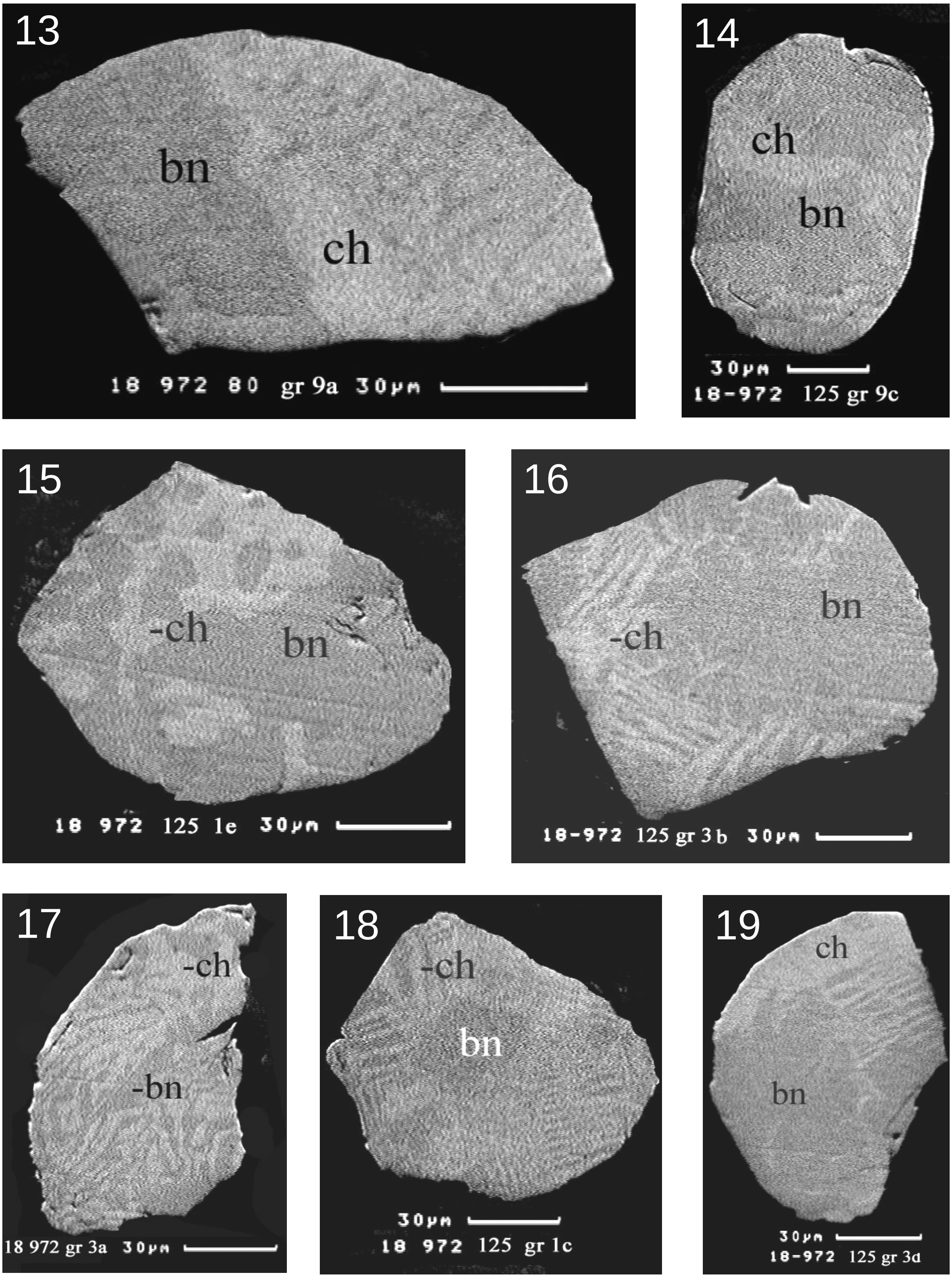

8
bn
ch
18-972 80 gr c 30μm

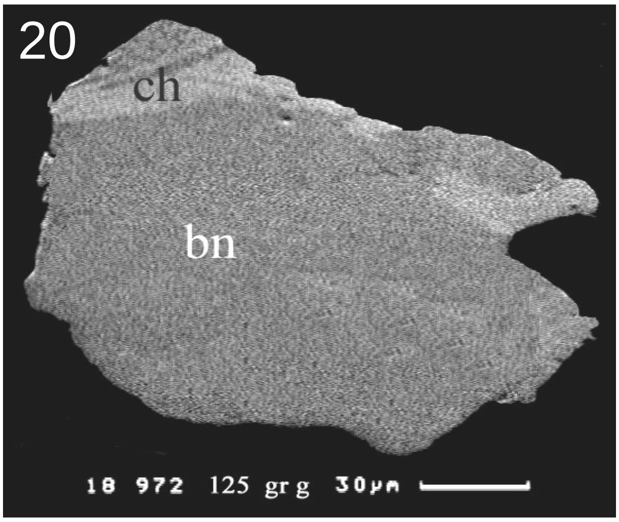

9
-bn
ch
18-972 125 gr 9b 30μm

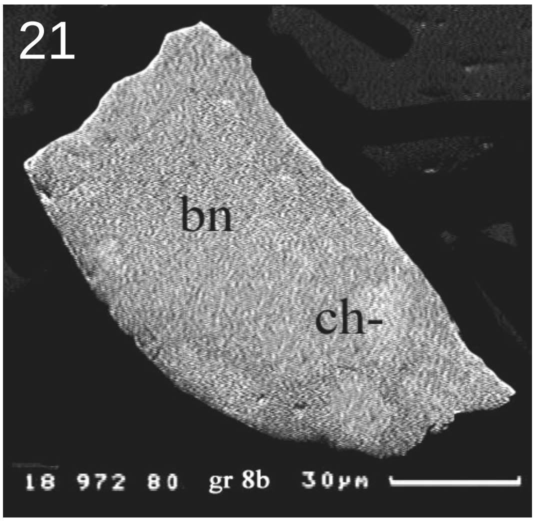

10
ch
bn
18-972 125 gr 9a 30μm

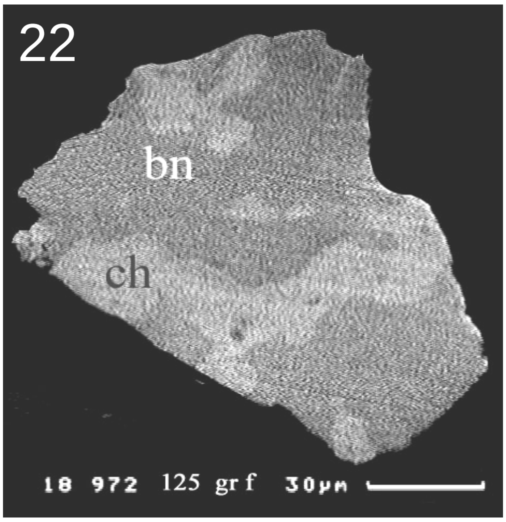

11
ch
bn
18 972 125 gr e 30μm

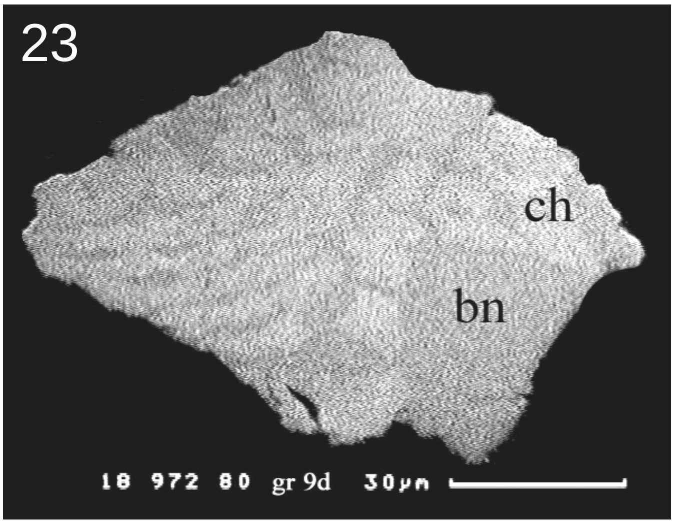

12
-bn
ch
30μm
18 972 80 gr 8c

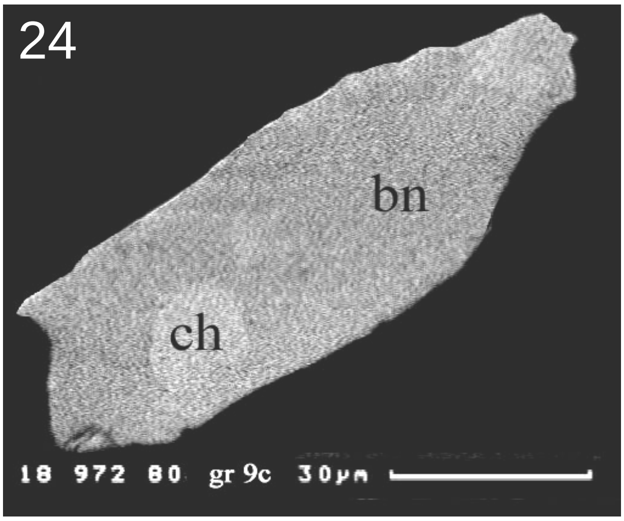

13
bn
ch
18 972 80 gr 9a 30μm
14
ch
bn
30μm
18-972 125 gr 9c
15
-ch
bn
18 972 125 1e 30μm
16
-ch
bn
18-972 125 gr 3b 30μm
17
-ch
-bn
18 972 gr 3a 30μm
18
-ch
bn
30μm
18 972 125 gr 1c
19
ch
bn
30μm
18-972 125 gr 3d

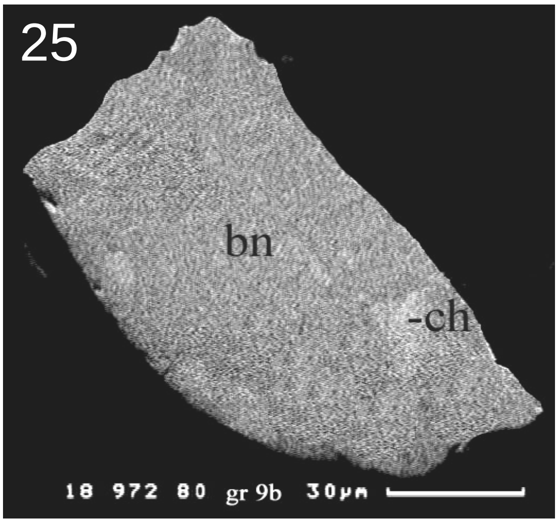

20
ch
bn
18 972 125 gr g 30µm

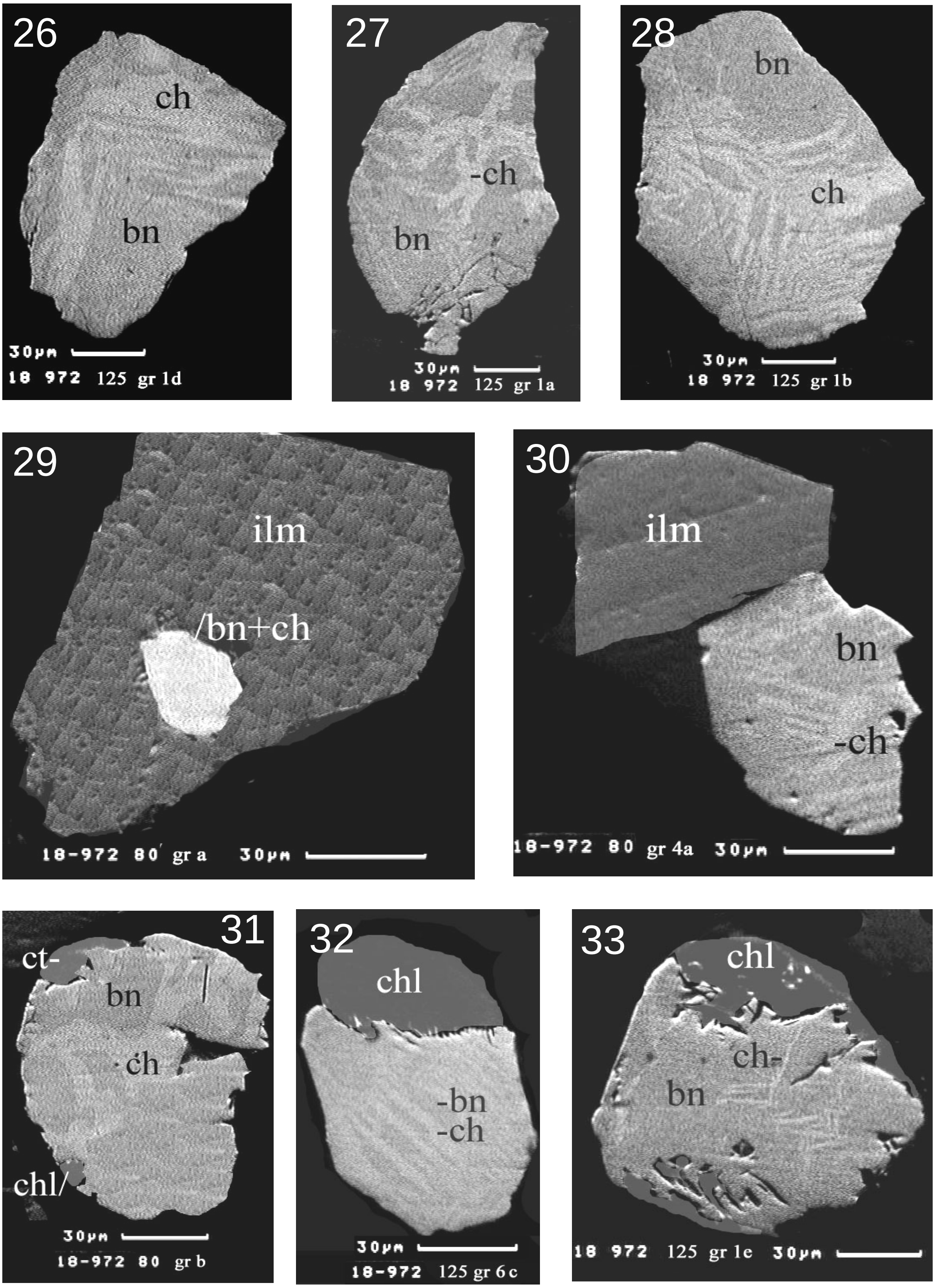

21
bn
ch-
18 972 80 gr 8b 30µm

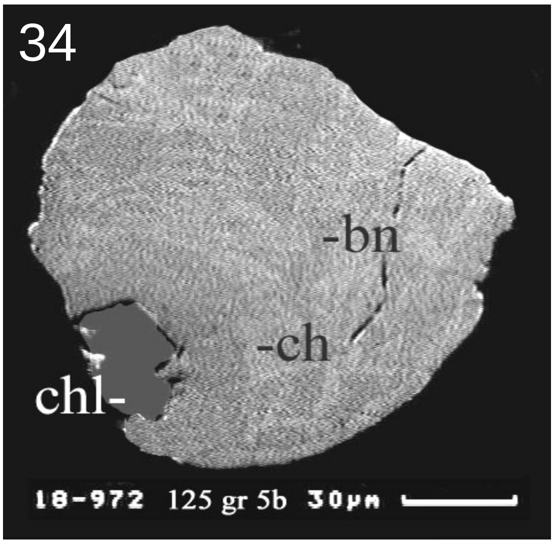

22
bn
ch
18 972 125 gr f 30µm

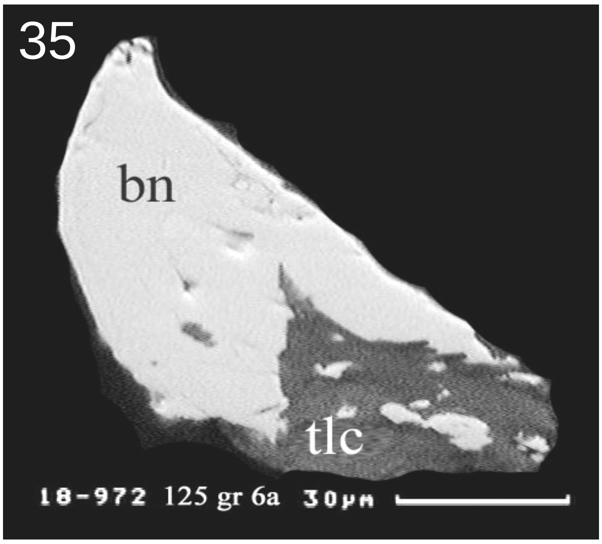

23
ch
bn
18 972 80 gr 9d 30µm

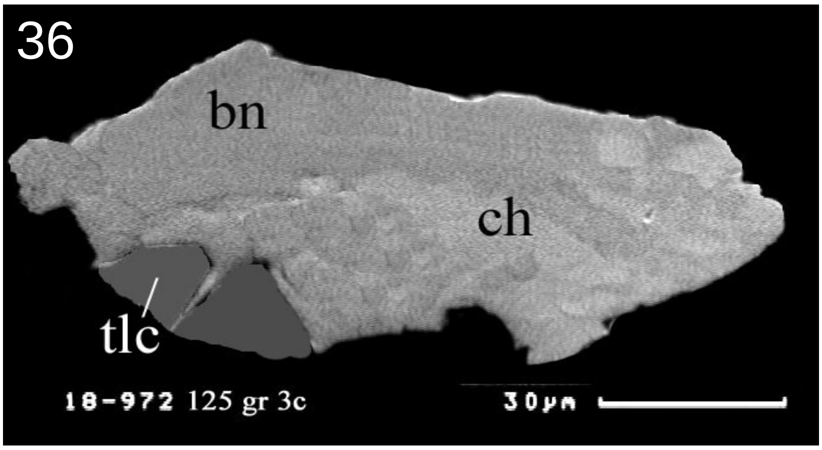

24
bn
ch
18 972 80 gr 9c 30µm


25
bn
-ch
18 972 80 gr 9b 30µm


26
ch
bn
30μm
18 972 125 gr 1d
27
-ch
bn
30μm
18 972 125 gr 1a
28
bn
ch
30μm
18 972 125 gr 1b
29
ilm
/bn+ch
18-972 80′ gr a 30μm
30
ilm
bn
-ch
18-972 80 gr 4a 30μm
31
ct-
bn
ch
chl/
30μm
18-972 80 gr b
32
chl
-bn
-ch
30μm
18-972 125 gr 6c
33
chl
ch-
bn
18 972 125 gr 1e 30μm


34
-bn
-ch
chl-
18-972 125 gr 5b 30μm


35
bn
tlc
18-972 125 gr 6a 30μm


36
bn
ch
tlc
18-972 125 gr 3c
30μm

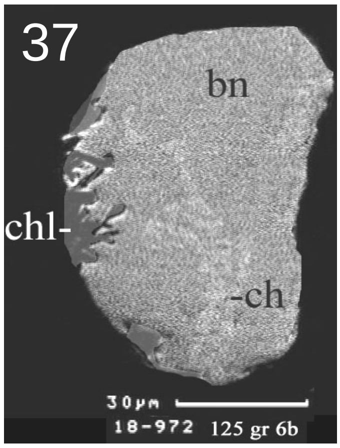
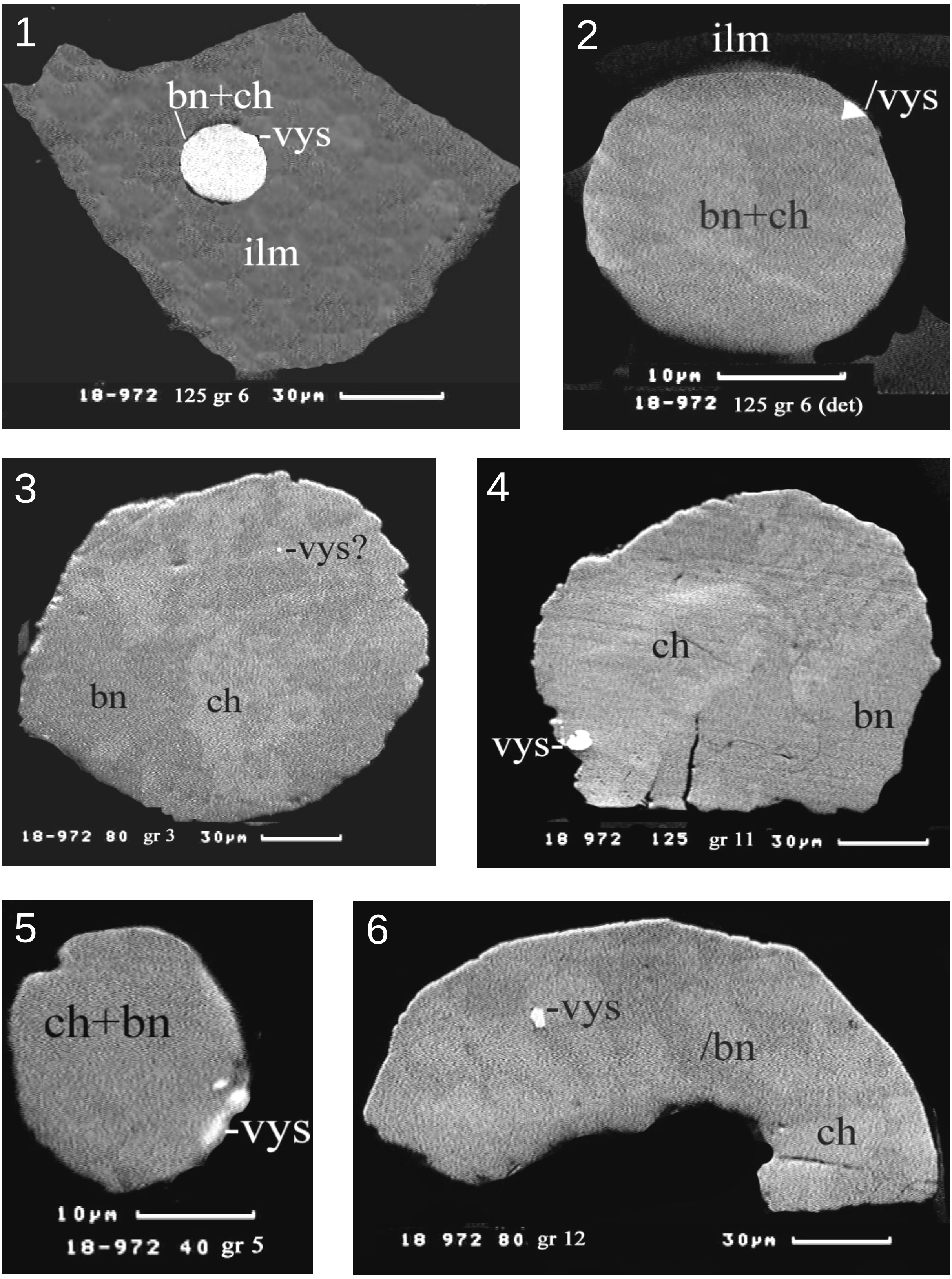
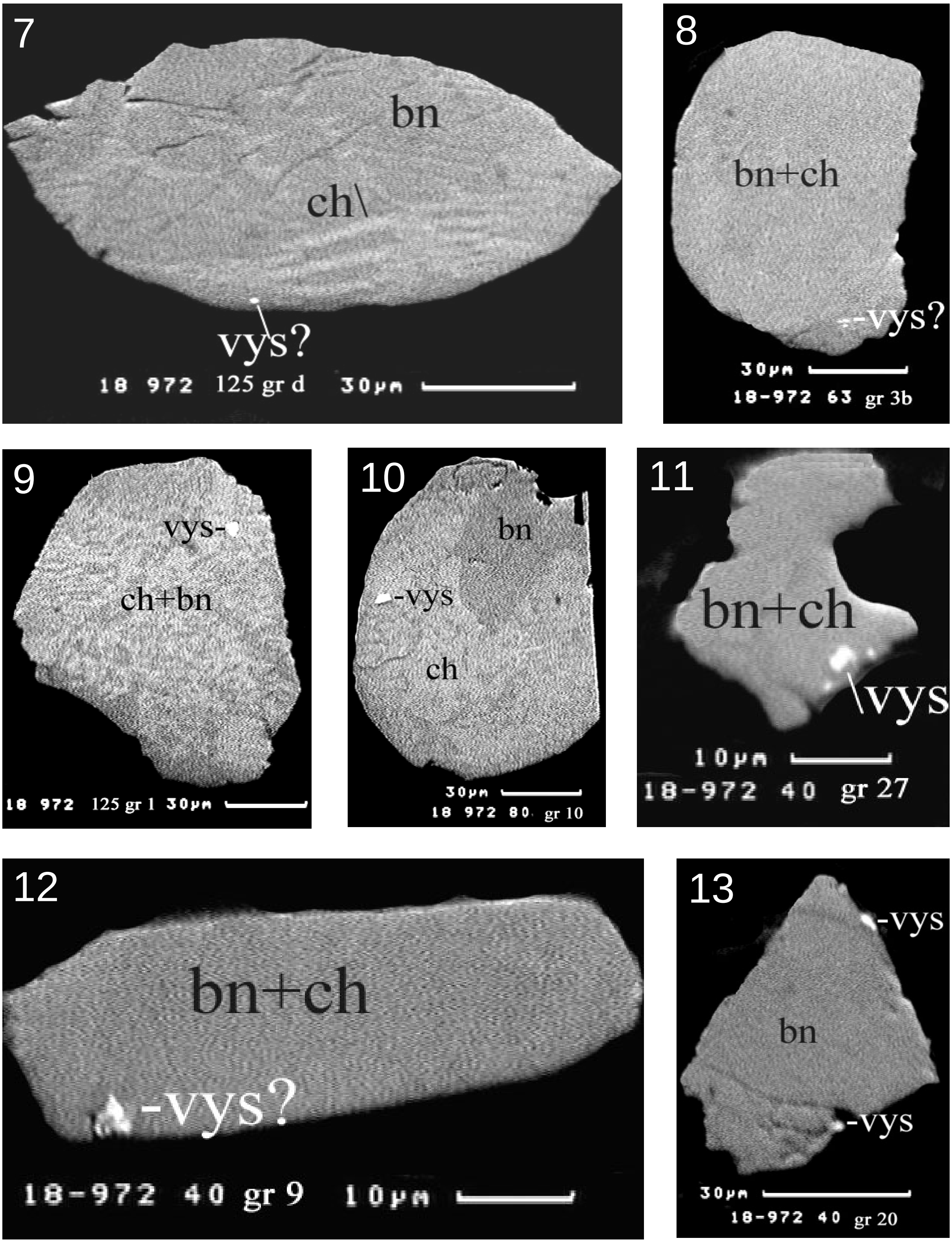
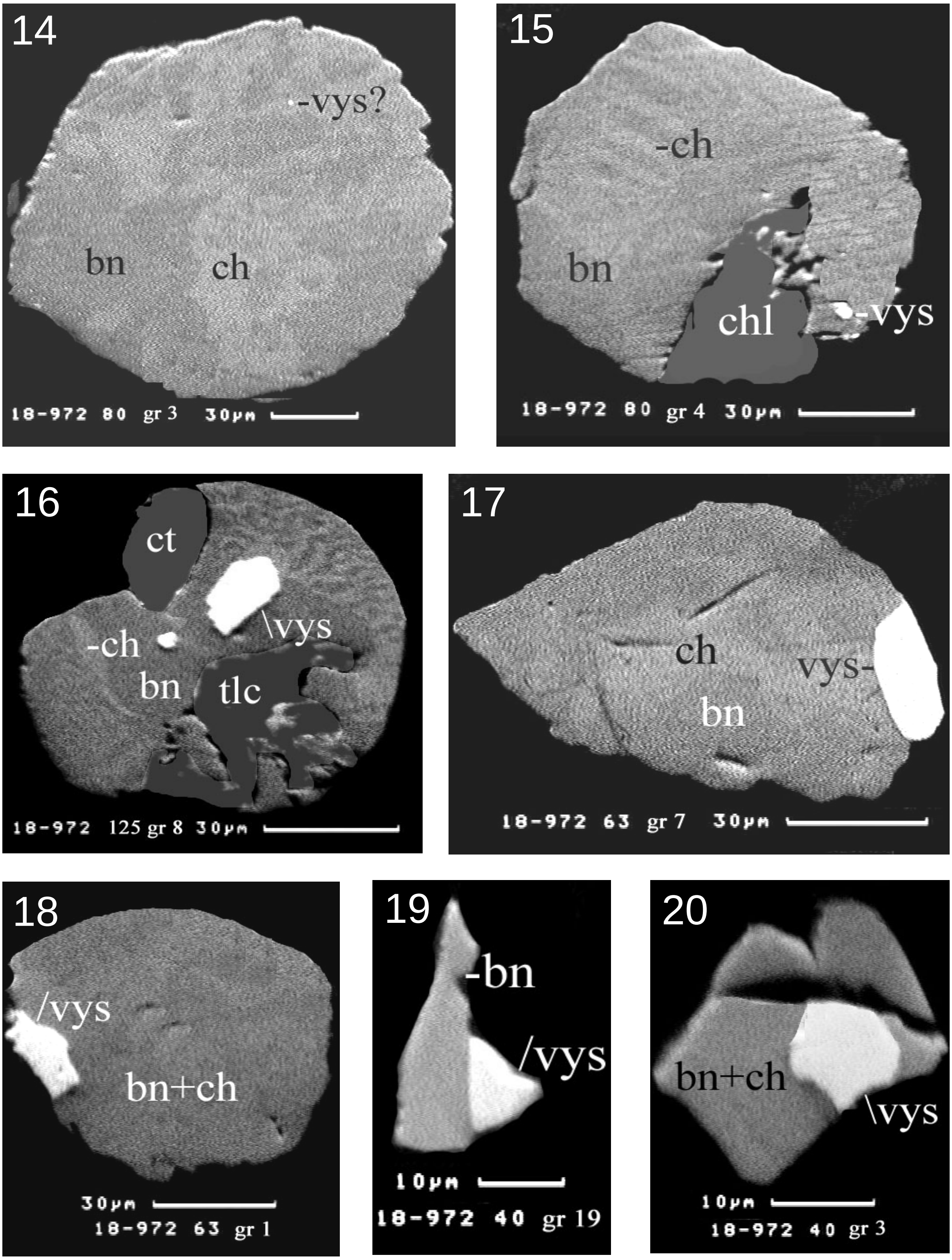

37
bn
chl-
-ch
30μm
18-972 125 gr 6b

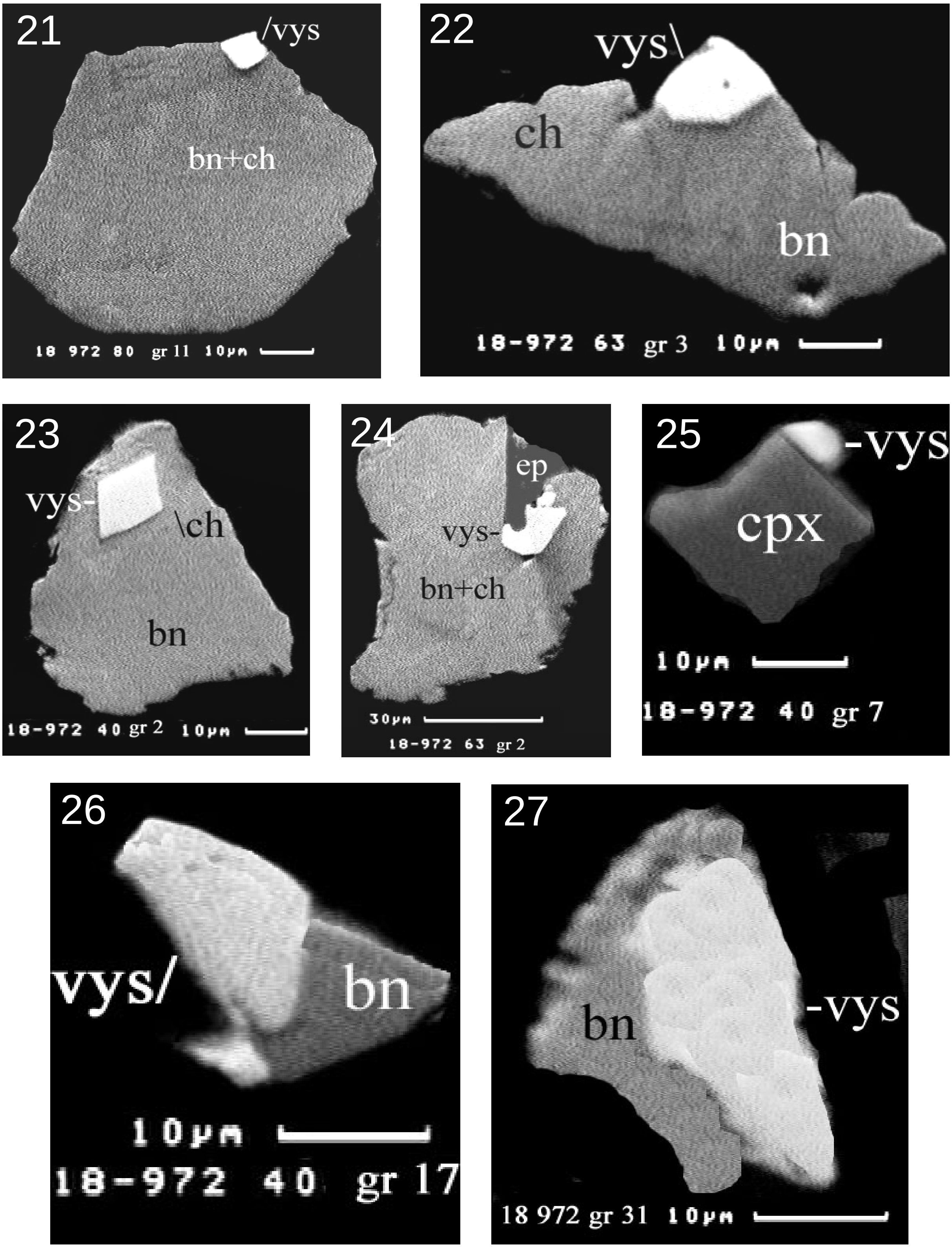
Plate 5

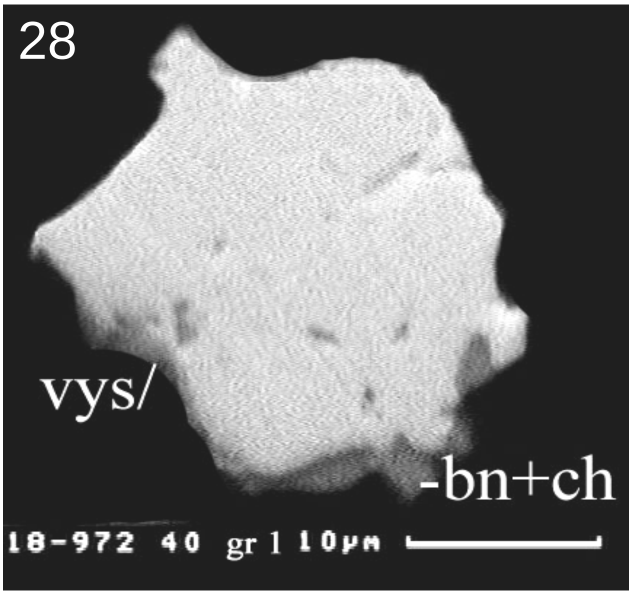
Sulphide globules and grains with inclusions of vysotskite (**bms**), vysotskite particles attached base metal sulphides (**bms-L**), vysotskite particles attached base metal sulphides and gangue (**sag**) or vysotskite attached to gangue (**ag**) - in heavy concentrates of the sample 90-18 972 (1-29); polished section, SEM-image (BIE); vys – vysotskite, bn – bornite, ch – chalcosine, ilm – ilmenite, cpx – clinopyroxene, tlc - talc, chl – chlorite, ct – calcite, ep – epidote.


1
bn+ch
-vys
ilm
18-972 125 gr 6 30µm
2
ilm
/vys
bn+ch
10µm
18-972 125 gr 6 (det)
3
-vys?
bn
ch
18-972 80 gr 3 30µm
4
ch
bn
vys-
18 972 125 gr 11 30µm
5
ch+bn
-vys
10µm
18-972 40 gr 5
6
-vys
/bn
ch
18 972 80 gr 12
30µm


7
bn
ch\
vys?
18 972 125 gr d 30µm
8
bn+ch
-vys?
30µm
18-972 63 gr 3b
9
vys-
ch+bn
18 972 125 gr 1 30µm
10
bn
-vys
ch
30µm
18 972 80 gr 10
11
bn+ch
\vys
10µm
18-972 40 gr 27
12
bn+ch
-vys?
18-972 40 gr 9 10µm
13
-vys
bn
-vys
30µm
18-972 40 gr 20


14
-vys?
bn
ch
18-972 80 gr 3 30µm
15
-ch
bn
chl
-vys
18-972 80 gr 4 30µm
16
ct
\vys
-ch
bn
tlc
18-972 125 gr 8 30µm
17
ch
vys-
bn
18-972 63 gr 7 30µm
18
/vys
bn+ch
30µm
18-972 63 gr 1
19
-bn
/vys
10µm
18-972 40 gr 19
20
bn+ch
\vys
10µm
18-972 40 gr 3


21
/vys
bn+ch
18 972 80 gr 11 10μm
22
vys\
ch
bn
18-972 63 gr 3 10μm
23
vys-
\ch
bn
18-972 40 gr 2 10μm
24
ep
vys-
bn+ch
30μm
18-972 63 gr 2
25
-vys
cpx
10μm
18-972 40 gr 7
26
vys/
bn
10μm
18-972 40 gr 17
27
bn
-vys
18 972 gr 31 10μm


28
vys/
-bn+ch
18-972 40 gr 1 10µm

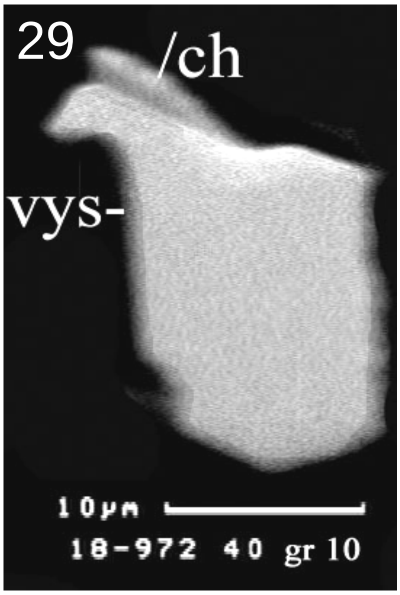
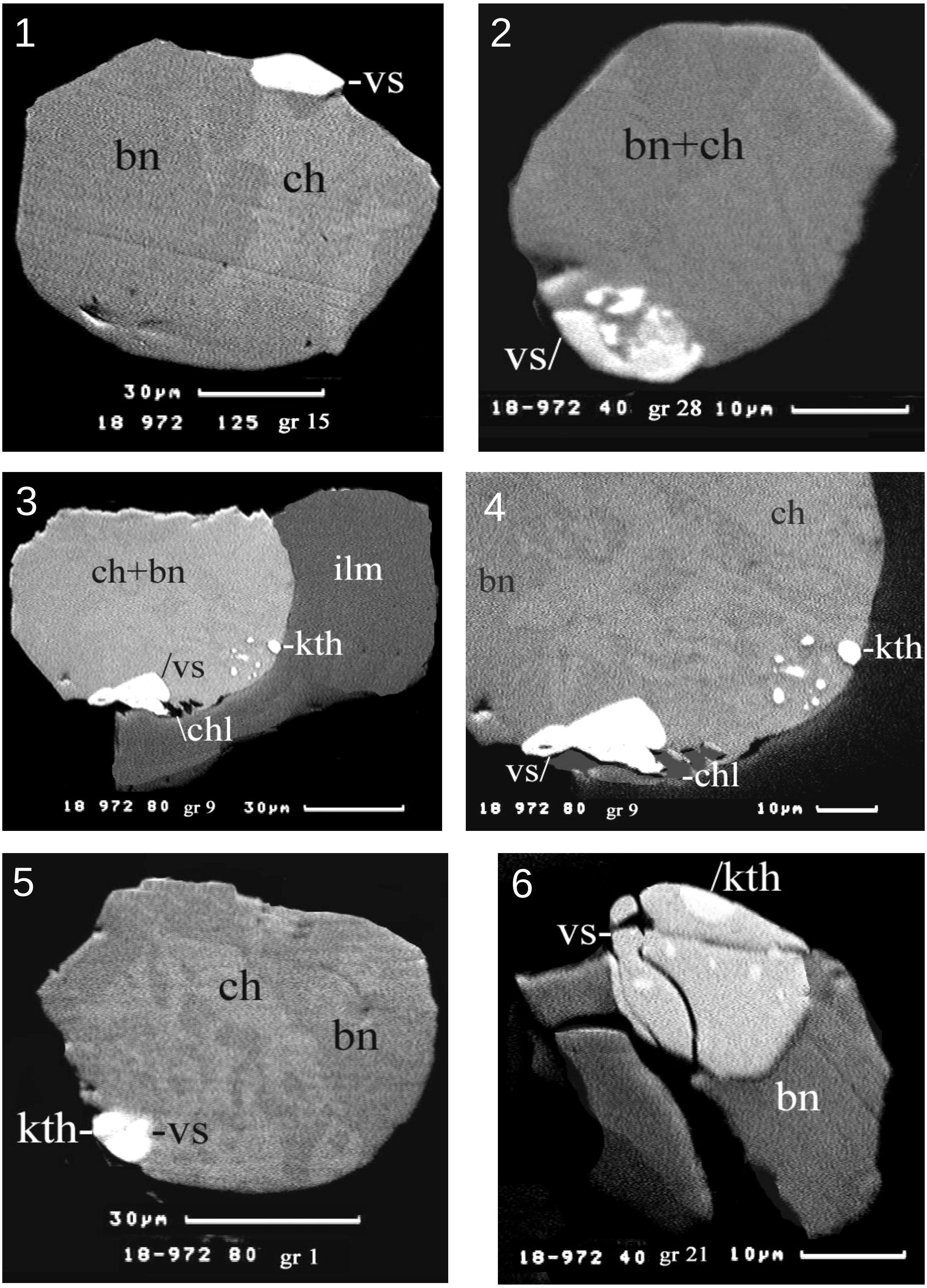
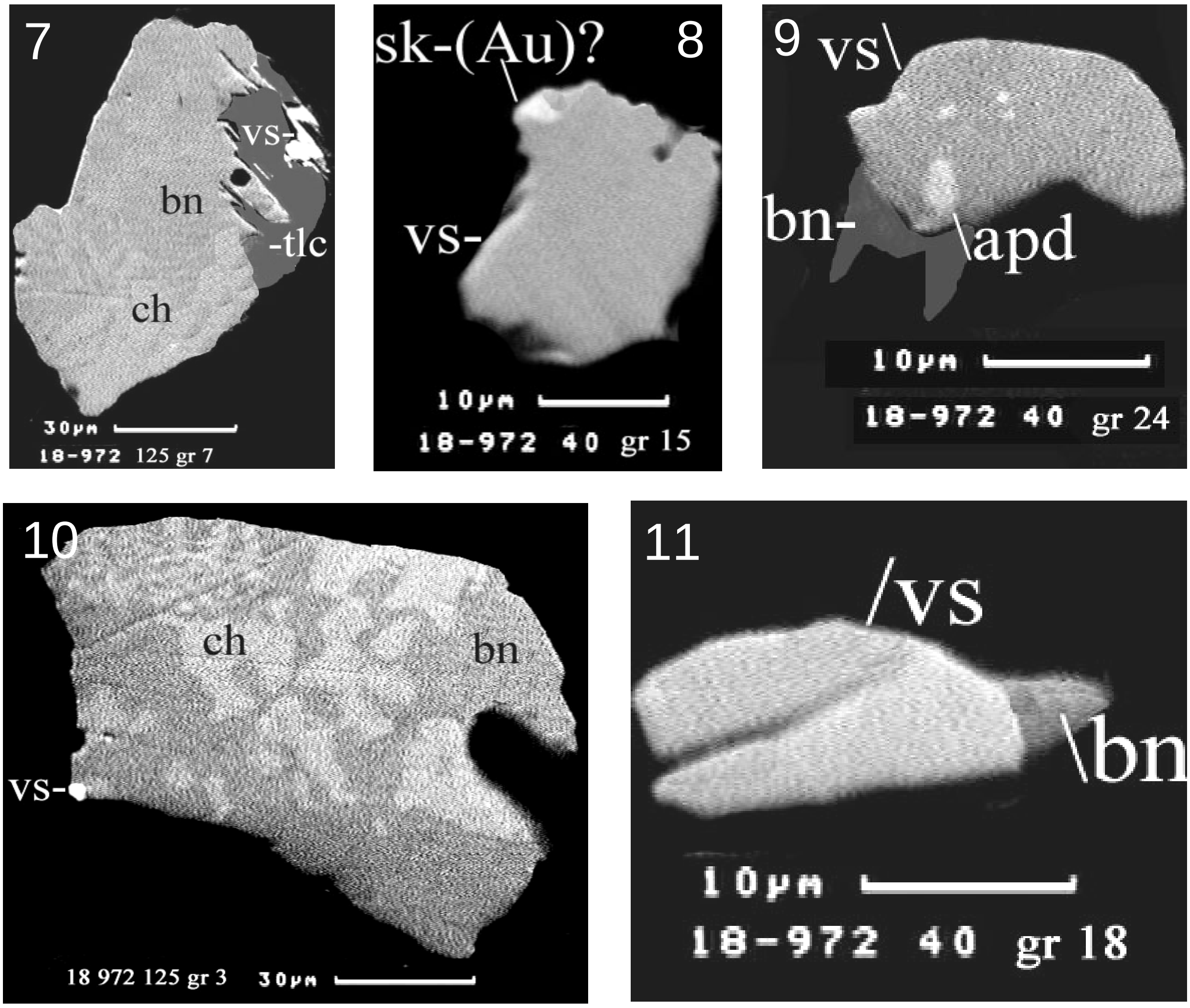

29
/ch
vys-
10µm
18-972 40 gr 10

Plate 6

Sulphide globules and irregular form grains with inclusions of vasilite (**bms**), vasilite particles attached base metal sulphides (**bms-L**), vasilite attached base metal sulphides and gangue (**sag**) or liberated vasilite grains attached other PGMs (L^+)- in heavy concentrates of the sample 90-18 972 (1-11); polished section, SEM-image (BIE); vs – vasilite, kth – keithconnite, apd – arsenopalladinite, sk-(Au) – skaergaardite enriched in Au, bn – bornite, ch – chalcosine, ilm - ilmenite, chl – chlorite, tlc – talc

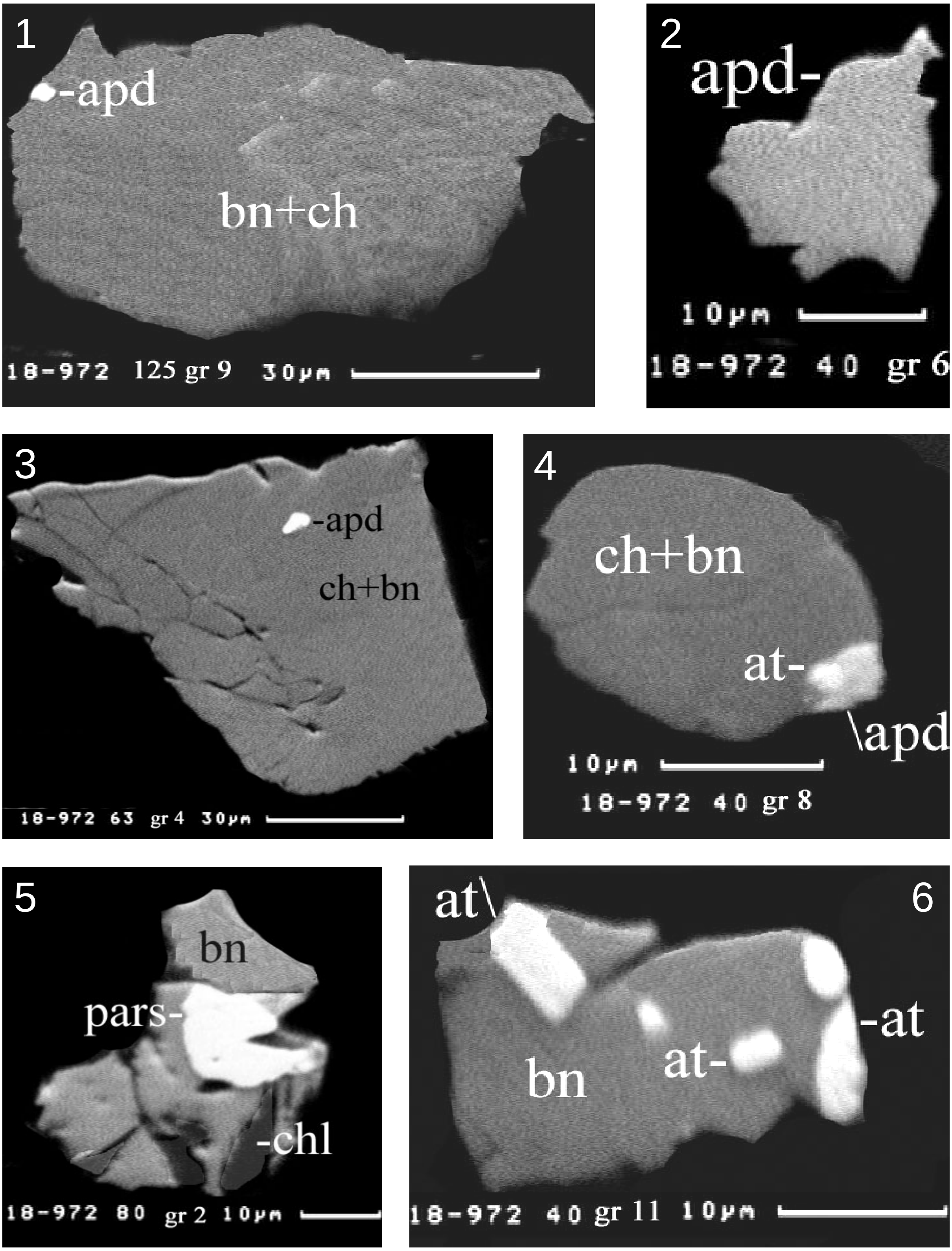

1
-vs
bn
ch
30μm
18 972 125 gr 15
2
bn+ch
vs/
18-972 40 gr 28 10μm
3
ch+bn
ilm
-kth
/vs
\chl
18 972 80 gr 9 30μm
4
ch
bn
-kth
vs/
-chl
18 972 80 gr 9 10μm
5
ch
bn
kth-
-vs
30μm
18-972 80 gr 1
6
/kth
vs-
bn
18-972 40 gr 21 10μm

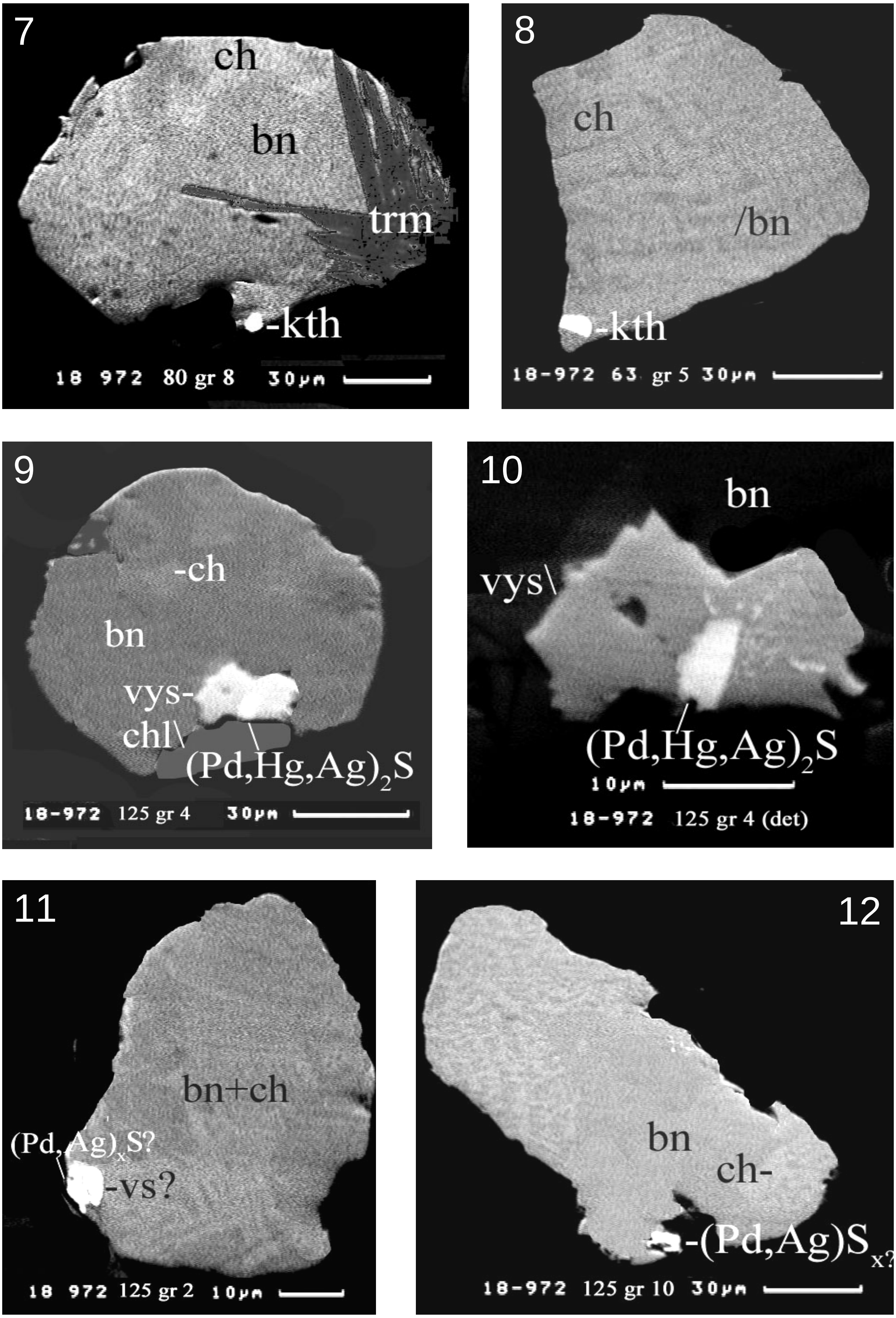

7
vs-
bn
-tlc
ch
30µm
18-972 125 gr 7
sk-(Au)?
8
vs-
10µm
18-972 40 gr 15
9
vs\
bn-
\apd
10µm
18-972 40 gr 24
10
ch
bn
vs-
18 972 125 gr 3
30µm
11
/vs
\bn
10µm
18-972 40 gr 18

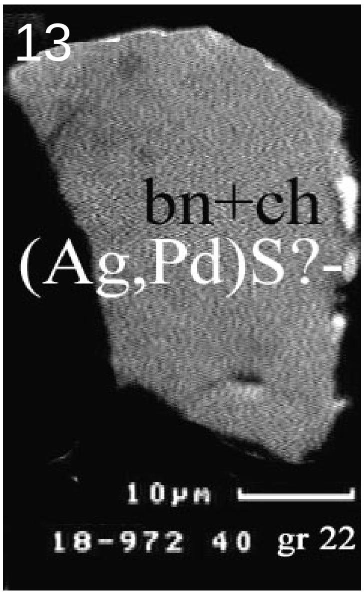
.

Plate 7

PGM grains containing arsenopalladinite (apd, 1-4), palladoarsenide (pars, 5), Atokite (at, 4, 6), keithconnite (kth, 7-8), skaergaardite (sk, 14), unnamed $(Pd,Hg,Ag)_2S$ (9, 10), and $(Pd,Ag)S_{x?}$ (11-13) in heavy concentrates of the sample 90-18 972; polished section, SEM-image (BIE); vys – vysotskite, vs – vasilite, bn – bornite, ch – chalcosine, chl – chlorite, trm – tremolite.


1
-apd
bn+ch
18-972 125 gr 9 30μm
2
apd-
10μm
18-972 40 gr 6
3
-apd
ch+bn
18-972 63 gr 4 30μm
4
ch+bn
at-
\apd
10μm
18-972 40 gr 8
5
bn
pars-
-chl
18-972 80 gr 2 10μm
at\
6
-at
at-
bn
18-972 40 gr 11 10μm


7
ch
bn
trm
-kth
18 972 80 gr 8 30μm
8
ch
/bn
-kth
18-972 63 gr 5 30μm
9
-ch
bn
vys-
chl\
(Pd,Hg,Ag)$_2$S
18-972 125 gr 4 30μm
10
bn
vys\
(Pd,Hg,Ag)$_2$S
10μm
18-972 125 gr 4 (det)
11
bn+ch
(Pd,Ag)$_x$S?
-vs?
18 972 125 gr 2 10μm
12
bn
ch-
-(Pd,Ag)S$_{x?}$
18-972 125 gr 10 30μm


13
bn+ch
(Ag,Pd)S?
10µm
18-972 40 gr 22

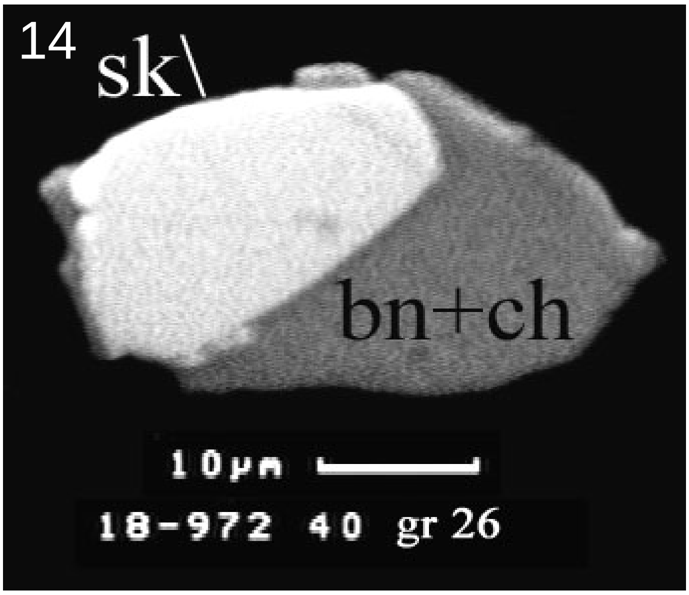
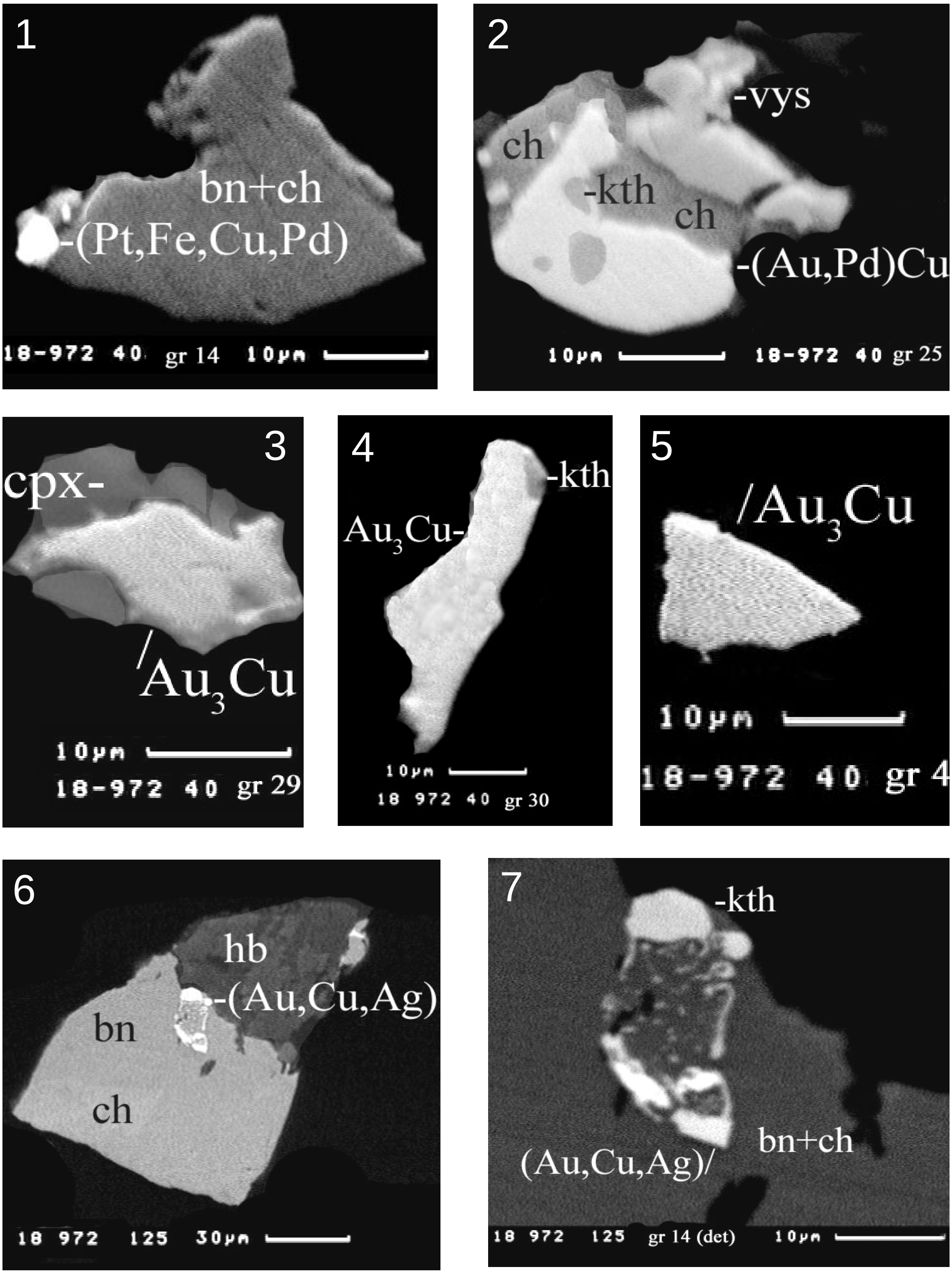
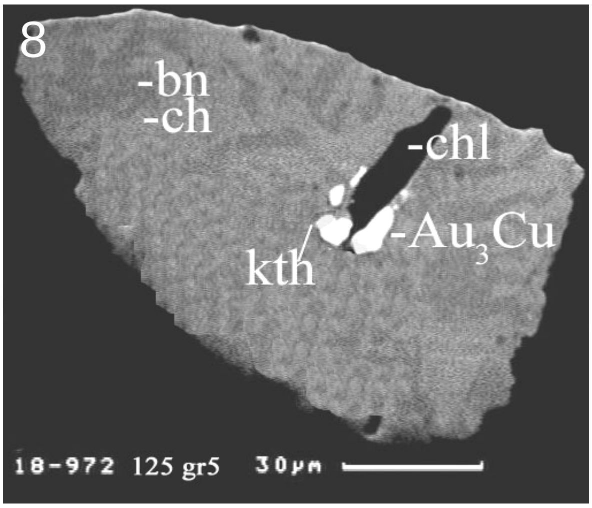
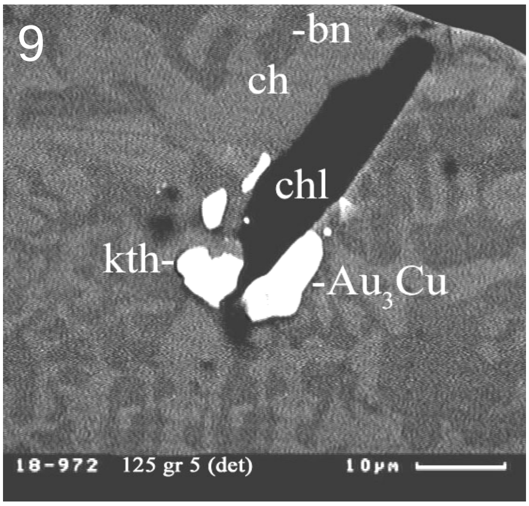

14
sk
bn+ch
10µm
18-972 40 gr 26

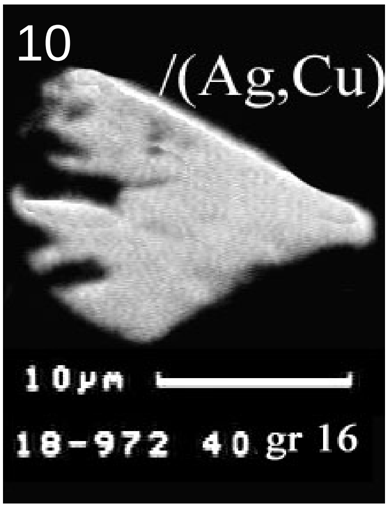
Plate 8

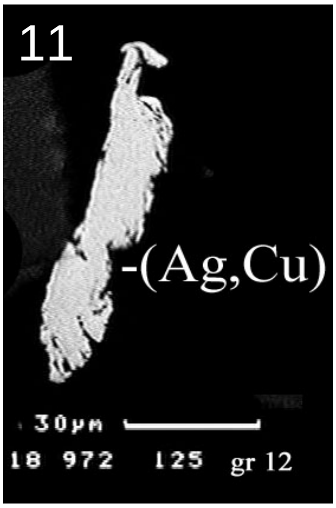
Grains of platinum (1) gold (2-9) and silver (10-13) alloys in heavy concentrates of sample 90-18 972; polished section, SEM-image (BIE); vys –vysotskite, kth – keithconnite, bn – bornite, ch – chalcosine, cpx – clinopyroxene, chl – chlorite, hb – hornblende; 7 part of 6; 9 part of 8.

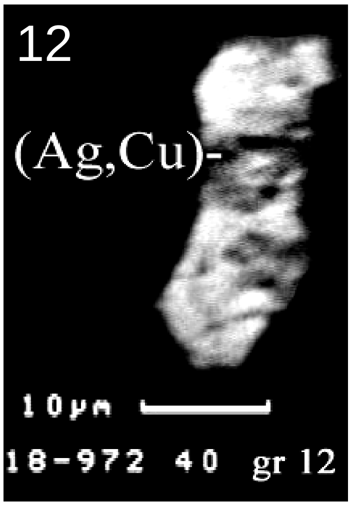

1
bn+ch
-(Pt,Fe,Cu,Pd)
18-972 40 gr 14 10μm
2
-vys
ch
-kth
ch
-(Au,Pd)Cu
10μm 18-972 40 gr 25
cpx-
3
/Au3Cu
10μm
18-972 40 gr 29
4
-kth
Au3Cu-
10μm
18 972 40 gr 30
5
/Au3Cu
10μm
18-972 40 gr 4
6
hb
-(Au,Cu,Ag)
bn
ch
18 972 125 30μm
7
-kth
bn+ch
(Au,Cu,Ag)/
18 972 125 gr 14 (det) 10μm

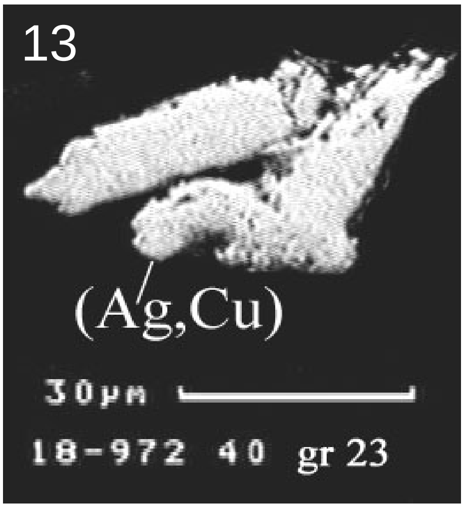

8
-bn
-ch
-chl
kth
-Au_3Cu
18-972 125 gr5 30μm


9
-bn
ch
chl
kth-
-Au_3Cu
18-972 125 gr 5 (det) 10μm


10
(Ag,Cu)
10μm
18-972 40 gr 16


11
-(Ag,Cu)
30μm
18 972 125 gr 12


12
(Ag,Cu)-
10μm
18-972 40 gr 12


13
(Ag,Cu)
30μm
18-972 40 gr 23