DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/93

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Part 14: Sample 90-10 434

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G E U S

Abstract

The report presents the results of a mineralogical investigation of sample 90-10 434 from the Skaergaard PGE-Au mineralisation. It samples the main Au-rich level in between 434 and 435 m in core 90-10 from the western margin of the intrusion. The mineralised level is equivalent to Pd-level Pd4a. Assays give 529 ppb Pd, 1587 ppb Au, and 35 ppb Pt for this interval.

The 703 g sample was crushed in small portions using a shatter box with small cavities (200 ml) for short periods (0.3-0.5 min) and sieved to remove the fine fraction (sieve - 100 μm) after each crushing session. The residual coarse fraction >100 μm was re-crushed until the entire sample has attained the desired maximum grain size.

After complete crushing all material was sieved through the following sieves: 1) <40, 2) 40-70, 3)70-100, 4) >100 μm. The fractions were then subjected to wet magnetic separation. None of the magnetic fractions contained precious metal grains.

The non-magnetic part of every grain size fraction was processed using the computer controlled hydroseparator CNT-HS-11. Monolayer polished sections were produced for each grain size fraction from the heavy mineral HS-concentrates of each fraction. The polished sections and one section of the bulk rock were investigated under the scanning electron microprobe.

The gabbro in the sample 90-18 1001 does not show the otherwise characteristic reaction relationships between cumulus and inter-cumulus phases, such as rims of olivine at the boundaries between Fe-Ti-oxides and pyroxenes.

The HS-concentrates contain numerous sulphide grains identified as sulphide droplets. They are composed of one or two Cu-Fe-sulphides – bornite and chalcopyrite, sometimes of pentlandite, pyrrhotite, tetrahedrite, gudmundite and clausthalite. Some of these sulphide grains contain inclusions of (Au,Cu,Ag,Pd) alloys and PGMs.

Grains of bornite and chalcopyrite, including irregular shaped aggregates form characteristic droplet like microglobules. These particles have characteristic exsolution textures with chalcopyrite lamellae in bornite matrix.

For a detailed study we selected 89 representative particles containing precious metal minerals. The precious metal minerals can be divided on two groups: 1) Alloys of (Au,Cu,Ag,Pd) including: a) (Au,Cu,Ag) alloy (83.3 %), b) (Au,Cu,Pd) alloy (1.4 %), c) (Au,Ag,Cu) alloy (2.8 %), and d) (Ag,Cu) alloy (5.2 %); 2) PGMs including: 1) arsenopalladinite, guanglinite, palladoarsenide, sperrylite, kotulskite, vysotskite, atokite (in total 7.2 % at all), and 2) hessite (0.1 %). The grain size (ECD) of the precious metal minerals varies between 6.2 and 58.3 μm with an average of 26 μm.

The precious metals are contained in: 1) (Au,Cu,Ag,Pd) alloys, which are enriched in Au, sometimes by Ag to (Au,Ag) alloy poor in Pd and Cu; 2) Pd-arsenides (palladoarsenide, guanglinite and arsenopalladinite) as well as Pd- and Ag-tellurides (kotulskite and hessite).

Many grains of (Au,Cu,Ag) alloys which are included in Cu-Fe sulphides as well as liberated once have the characteristic droplet-like rounded shapes.

Apart from two PGM-particles (vysotskite and arsenopalladinite) which do not contain (Au,Cu,Ag,Pd) alloys in their association, all other PGM grains including arsenides (arsenopalladinite, guanglinite, palladoarsenide, sperrylite) and tellurides (kotulskite) form rims on gold mineral grains The paragenesis with Cu-Fe sulphides is characteristic for both - (Au,Cu,Pd) alloys and PGMs.

New mineralogical data suggests reaction between Au-rich minerals Te- and As-containing melt/fluid. The sample originates from the top of the precious metal mineralisation in a marginal core and the later crystallized gabbros are barren. The host gabbro trapped residual liquid and the rimming of primary Au-rich alloys reflects reaction between formed precious metal minerals and residual metal-bearing fluid.

Intodoction

The report describes the mineralogy of sample 90-10 434 from the main Au level in core 90-10 from the “Platinova Reef” of the Skaergaard intrusion (Andersen et al, 1998). In core 90-10 the main concentration of gold is found at the Pd4a level (Nielsen et al. 2007).

The report is based on the data obtained from concentrates of PGMs produced using Hydroseparator CNT-HS-11 and polished section of the bulk rock. Mounts with concentrates and a polished section of the gabbro were studied under the electron microscope and the electron microprobe (Camscan-4DV, Link AN-10 000). The report describes of the grain characteristics, the parageneses and the compositional variation of minerals of the host gabbro, the sulphide droplets, and PGMs and precious metal alloys.

The investigation was carried out in 2010.

Sample 90-10 434

Sample 90-10 434 was collected from BQ drill core # 90-10, 434.0-435.0 m interval. The 703 g sample collects Au(Pd4a) level in core 90-10. Assays give 529 ppb Pd, 1587 ppb Au, and 35 ppb Pt for this interval. The core has previously been sampled for other purposes and smaller sections of the meter interval are not represented in the core. The sample collects 1/3 of the diameter of the preserved core.

Analytical techniques

Analytical techniques are described in Nielsen et al. (2003). The heavy mineral HS-concentrates with precious metal minerals were received by means of new patented model of computer controlled Hydroseparator CNT-HS-11 and newly patented glass separation tube (GST). One polished section was prepared from the fragment of the rock sample (Plate 1).

The remaining core material was crushed to –100 μm. After complete grinding, the sample was wet-sieved into the following fractions: <40 μm (359 g), 40-70 μm (155 g), 70-100 μm (123 g), >100 μm (34 g, not studied).After wet magnetic separation, grain size fractions: <40 μm, 40-70 μm, 70-100 μm were density separated using Hydroseparator CNT-HS-11. Several polished monolayer sections were produced from the heavy HS-concentrates (Plate 2).

Results

Rock forming minerals and sulphide mineralogy

Silicates and oxides

The silicates and FeTi-oxides related to sulphides and precious metal phases are: 1) *plagioclase*, $An_{45-48,}$ average An_{46} (Table 1, analyses 1-4, average analysis 5); 2) monoclinic ferrous *pyroxene*, Mg# = 0.588-0.610 , average Mg# = 0.602 (Table 1, analyses 6-9, average analysis 10), 3) orthorhombic ferrous *pyroxene*, Mg# = 0.497-0.513, average Mg# = 0.505 (Table 1, analyses 11-14, average analysis 15) and Fe-Ti oxides including 4) *ilmenite* (Table1, analyses 23-26, average analysis 27), and 5) *titaniferous magnetite*, TiO_2 3.9-14.1 wt. %, average 8.5 % (Table 1, analyses 16-21, average analysis 22) monoclinic and orthorhombic pyroxenes form typical exsolution texture (Plate 1, #*1, 7, 8*).

The Fe-Ti-oxides occur as aggregates of 1-3 mm, anhedral grains. They fill spaces between plagioclase and pyroxene grains (Plate 1, #*2-6*).

Gabbro of the studied polished section from the sample 90-10, 434 does not have characteristic structures of reactionary relationships of cumulus and inter cumulus phases i.e. rims at the boundaries between accumulated grains of Fe-Ti-oxides and two-pyroxenes.

The Fe-Ti-oxides occur as aggregates of 1-3 mm anhedral grains. They fill space between apparently resorbed grains of plagioclase and pyroxenes (see Plate 1). The studied fragment of the gabbro of sample 90-18 1001 does not show the otherwise characteristic olivine rims between cumulus and inter-cumulus phases (e.g., Holness et al, 2011). The samples does contain a few grains of quartz, that is otherwise extremely rare in MZ gabbros. The absence of olivine rims could be related to the presence of quartz in the interstices of the sample.

Sulphides

Fine inclusions of chalcopyrite are observed in exsolution pyroxene (Plate 1, #*7, 8*) and irregular chalcopyrite grains are associated with late stage quartz and chlorite (Plate 1, #*8*). Compared to these few observations the nonmagnetic heavy mineral HS-concentrates are ilmenite-rich products (>90% ilmenite) enriched in grains of base metal sulphides and precious metal minerals (Plate 2).

The sulphide grains are dominantly bornite or bornite+chalcopyrite, chalcopyrite is less common (>90% of the base metal sulphides, Plates 3 and 4). The terms of number of grains bornite-chalcopyrite and chalcopyrite grains represent ~40 % of all grains of base metal sulphides Relatively rare grains are composed of pentlandite and pyrrhotite and fewer of tetrahedrite, gudmundite and clausthalite (Plate 5).The relative proportions of base metal sulphides were estimated from a random selection of 150 grains in the monolayer sections.

Minerals in grain	Number of grains	%
Bornite	91	60.7
Bornite+halcopyrite	46	30.7
Chalcopyrite	10	6.7
Pentlandite	2	1.3
Pyrrhotite	1	0.7
Total	150	100

Mostly, the sulphides form:

1) droplet-like microglobules of bornite (Plate 3, #*1-4*) and bornite+chalcopyrite (Plate 4, #*1-3* etc)
2) irregular-shaped grains (see Plates 3-5). Bornite and chalcopyrite form classical exsolution (Plate 4, #*1, 4-11*).

Compositions of bornite (Table 2, analyses 1-18, average analysis 19) and chalcopyrite (Table 2, analyses 20-27, average analysis 28) are near-stoichiometric. The average composition of pentlandite (Table 2, analyses 29-30, average analysis 31) corresponds to formula $(Ni_{4.68}Fe_{4.27}Co_{0.05})_{7.00}S_{8.00}$. Pyrrhotite has the compositions (Plate 2, analyses 32) close to formula $(Fe,Ni)_7S_8$ which is characteristic for the monoclinic pyrrhotite modification.

Au-minerals and PGMs: recovery, grain size, and petrographic relations

Recovery

No grains of precious metal minerals could be identified in the one polished section of the gabbro. In strong contrast, the heavy mineral HS-concentrates have yielded 89 particles with Au-minerals and PGMs. At least 10 different Au-Ag-minerals and PGMs are documented in the sample 90-10, 434. They include:

1) *(Au,Cu,Ag,Pd)* alloys – in 84 particles
2) *arsenopalladinite* $(Pd,Cu,Fe,Au)_8As_3$ - in 15 particles
3) *guanglinite* $(Pd,Cu,Fe,Au)_3(As,Sn)$ – in 2 particles
4) *palladoarsenide* $(Pd,Pt,Cu,Fe)_2(As,Sn)$ - in 3 particles
5) *kotulskite* (Pd,Au)Te – in 10 particles
6) *vysotskite* PdS – one particle
7) *native silver* (Ag,Cu) – one particle
8) *sperrylite* $PtAs_2$ – in one particle

9) atokite Pd_3Sn – in one particle
10) hessite Ag_2Te – in one particle.

Based on the area of all recorded grains can the proportions between the precious metal phases be calculated (Table 3 and Figure 1).

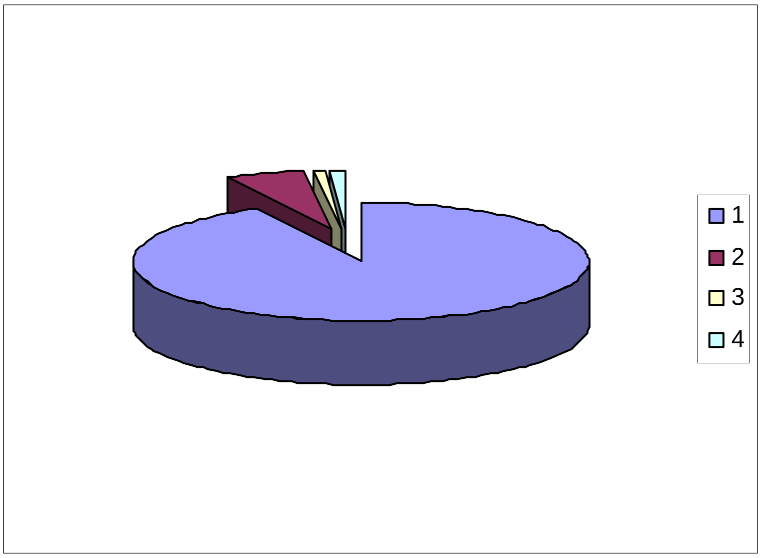

Fig.1. Relative contents of precious metal minerals in the heavy mineral HS-concentrates of the sample 90-10, 434 (see Table 3).

1) (Au,Cu,Ag,Pd) alloys and native Ag (92.6 %);
2) Pd arsenides (arsenopalladinite, guanglinite and palladoarsenide (5.5 % of all)
3) kotulskite and hessite (0.9 %);
4) vysotskite (1.0 %).

Grain size

The size of grains is measured from the effective diameter of a circle enclosing the grains (ECD) using the “imageJ” software. The grains are from 6.2 to 58.3 μm in size with an average of 26 μm (Tables 3 and 4). The histogram in Fig. 2 shows the sizes of 89 precious metal mineral grains. It is a normal distribution.

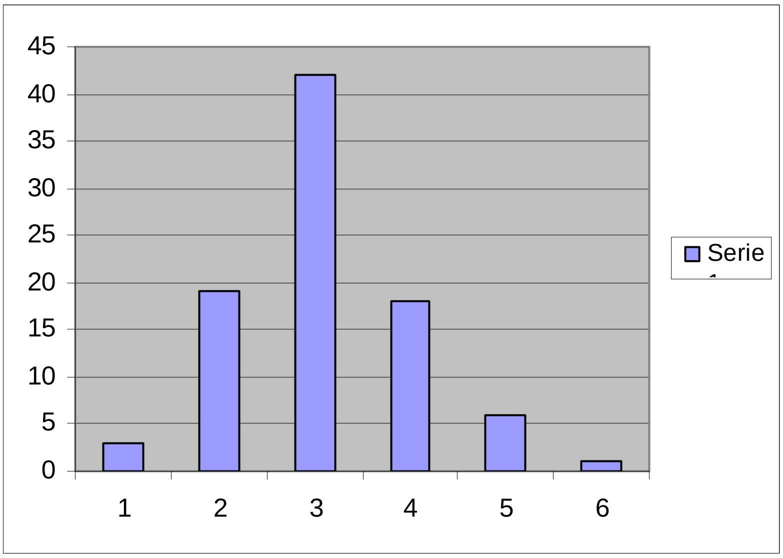

Fig 2. Histogram showing the grain size distribution of the precious metal minerals (n = 89) from the heavy mineral HS-concentrates of sample 90-10 434. The average size (ECD_{avr}) is 26 μm. The x-axis is divided at 10, 20, 30, 40 50 and 60 µm. The y-axis gives the number of grains within a grain size fraction. Total number of grains is 89.

Petrographic observations

The SEIs (scanning electron images) show that the majority of PGM grains are well preserved and have kept their primary shapes and sizes (Plates 6-10). The grains of precious metal minerals 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.

The method of disintegration allows record of the genetically most important information on mineralisation. The concentrates provide full information for the reconstruction of the primary shapes and sizes of accessory minerals, their parageneses and the relationship with the host rock.

In the HS heavy mineral concentrates of the sample 90-10 434 the precious metal mineral grains (n = 89) occur in the mineral associations shown in Figure 3 and Table 5. Three groups of associations of precious metal minerals can be distinguished:

1. liberated particles (associations **L** and **Lp**, 53.1 area %);
2. particles which are associated with Fe-Cu sulphides (associations **bms**, **bms-L**, **sag** and **sag-L**, total 36.5 area %);
3. particles which are associated with rock-forming minerals only (**ag** and **ag-L** associations, 10.3 area %).

Based on SEIs, images of precious metal minerals in the heavy mineral HS-concentrates can be divided into different groups:

1. liberated (Au,Cu,Ag) alloys (**L**- association) - (Plate 6);
2. (Au,Cu,Ag) alloys, associated with Cu-Fe sulphides (**bms**, **bms-L**, **sag**, **sag-L** associations) – (Plate 7);
3. (Au,Cu,Ag) alloys, associated with rock-forming minerals only (ag, ag-L associations) – (Plate 8);.
4. particles, containing arsenides of Pd and Pt (arsenopalladinite, guanglinite, palladoarsenide, sperrylite) - (Plate 9).
5. particles, containing Pd-tellurides (kotulskite), Pd-sulphides (vysotskite) and Ag-minerals (hessite and native silver) - (Plate 10).

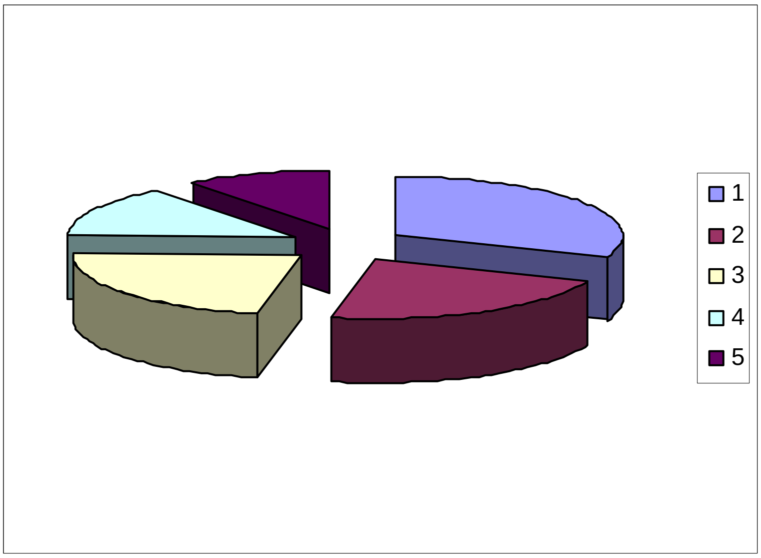

Fig. 3. PGE-minerals grouped by associations (sample 90-10, 434).

1 – **L** association (30.9 %); 2 – **Lp** association (22.2 %); 3 – **bms** and **bms-L** associations (22.8 % at all); 4 – **sag** and **sag-L** associations (13.8 % at all); 5 – **ag** and **ag-L** associations (10.3 % at all).

Description and composition of Au- minerals and PGMs

(Au,Cu,Ag,Pd) alloys

Description
(Au,Cu,Ag,Pd) alloys are the dominating precious metal minerals in the HS heavy mineral concentrates of the sample 90-10 434 (84 particles and 87.5 area % of all precious metal minerals). Except liberated grains (associations **L** and **Lp** – 52,7 area % at all) these alloys are associated with Cu-Fe sulphides (**bms**, **bms-L**, **sag**, **sag-L** associations – 35.2 area % at all) as well as with rock-forming minerals (**ag** and **ag-L** associations – 12.1 area % at all).

Many grains of Au-minerals are also associated with other PGMs, first of all Pd-tellurides (kotulskite – Plate 10, #*1-10*) and Pd-Pt-arsenides (arsenopalladinite, guanglinite, palladoarsenide and sperrylite – Plate 9, #*2-17*; Plate 10, #*7, 9*). These PGMs occur at the margin of gold-alloy grains (see Plates 9 and 10). Au-mineral-bearing sulphide particles preserved their primary very irregular, aggregate-shapes in the HS heavy mineral concentrates (see Plate 9, #*4, 5, 8, 10*; Plate 10, # *5, 6, 9, 10, 16*)

(Au,Cu,Ag,Pd) alloy, enclosed in sulphide as well as in liberated particles often occur as:

1) isometric droplet-like grains or particles with rounded outlines (Plate 6, #*1-4, 7*: Plate 7, # *1-9, 15*: Plate 9, #*9, 11, 12*; Plate 10, #*2* etc.)
2) irregular shaped grains and aggregates (Plate 6, #*8-25*; Plate 7*,* #*10-14*; Plate 8; Plate 9, #*2-8, 13-18;* Plate 10, #*1, 4-10* etc.).

Note should be taken that, the majority of the droplet-like gold mineral grains occur as inclusions in Cu-sulphide (see Plate 7, #*1, 2, 15* etc.), whereas irregular shape grains are always associated with rock-forming minerals (see Plate 8). Grain sizes of (Au,Cu,Pd,Ag) alloys vary from 6.1 to 46.2 µm with an average of 25 µm (Table 3).

Mineral chemistry
The chemical composition of (Au,Cu,Ag,Pd) alloys is given in 73 analyses from 73 individual particles (Table 6). The particles can be divided into 4 groups:

1. (Au,Cu,Ag) alloys is the dominant group. They are rich in Au relatively poor in Cu and Ag (Table 6, analyses 1-65); average composition (analysis 66, wt. %) – Au 93.2, Cu 4.2, Ag 2.2, Total 99.6;
2. Alloys with no Ag. (Au,Cu) alloy (Table 6, analyses 67-69); average composition (analysis 70, wt. %) – Au 94.6, Cu 5.6, Total 99.6;

3. Gold particles enriched in Ag. (Au,Ag,Cu) alloy (Table 6, analyses 71-73); average composition (analysis 74, wt. %) – Au 88.5, Ag 9.6, Cu 1.7, Total 99.8; this alloy also may not contain Cu (Table 6, analysis 75, wt. %) – Au 80.9, Ag 18.9, Total 99.0;
4. Gold particles enriched in Pd. (Au,Cu,Pd) alloy (Table 6, analyses 76, 77); average composition (analysis 78, wt. %) – Au 88.8, Cu 4.5, Pd 7.0, Total 99.5.

All of these are alloys with a dominant Cu-Au substitution.

Pd arsenides: arsenopalladinite $(Pd,Cu,Fe,Au)_8As_3$, guanglinite $(Pd,Cu,Fe,Au)_3(As,Sn)$ and palladoarsenide $(Pd,Pt,Cu,Fe)_2As$

Description

Except one arsenopalladinite grain which occur as an intergrowth with bornite (Plate 9, #*1*), all other particles with Pd-arsenides also contain (Au,Cu,Ag,Pd) alloys. The PGMs often also occur together with kotulskite and are found at the margin of gold mineral grains (Plate 9, #*2-13, 15-17*). Pd-arsenides, as well as (Au,Cu,Ag,Pd) alloys are very often associated with bornite and chalcopyrite (Plate 9, #*1, 5, 6, 9-11, 16*; Plate 10, #*9*) sometimes together with rock-forming pyroxenes and chlorite (Plate 9, #*6*; Plate 10, #*9*).

Arsenopalladinite $(Pd,Cu,Fe,Au)_8As_3$ is the most abundant of the Pd-arsenides (in 15 particles; 4.1 area % from all precious metal minerals). Less common are guanglinite $(Pd,Cu,Fe,Au)_3(As,Sn)$ (in 2 particles; 1.7 area %) and palladoarsenide $(Pd,Pt,Cu,Fe)_2As$ (in 3 particles; 2.5 area %). Two Pd-arsenides (arsesenopalladinite and palladoarsenide – Plate 10, #*9* and guanglinite and palladoarsenide – Plate 9, #*16*) can be found together in a single PGM-bearing particle. In such particles palladoarsenide is a late stage mineral.

Grains of Pd-arsenide have irregular shapes. The grains of arsenopalladinite vary in size between 7.1 and 21.4 µm and give an average of 12.8 µm. Guanglinite varies from 9.4 to 22.2 µm, and palladoarsenide from 2.3 to 10.9 µm (see Table 3).

Mineral chemistry

The composition of arsenopalladinite is given in 10 analyses in 10 particles (Table 7, analyses 1-10, average analysis 11). Typical substitutions in arsenopalladinite are: Au up to 2.1 % (Plate 7, analysis 2), Cu up to 3.3 % (analysis 9), and Fe up to 1.2 % (analysis 10).

The composition of guanglinite is given in 2 analyses in 2 particles (Table 7, analyses 12, 13; average analysis 14). Typical substitutions in guanglinite are: Au up to 1.6 % (Plate 7, analysis 13), Cu up to 2.5 % (analysis 12), Fe up to 0.9 % (analysis 12), and Sn up to 1.3 % (analysis 13).

The composition of palladoarsenide is given in 3 analyses in 3 particles (Table 7, analyses 15-17; average analysis 18). Typical substitutions in guanglinite are: Pt up to 12.4 % (Plate 7, analysis 15), Cu up to 2.9 % (analysis 17), Fe up to 1.0 % (analysis 15), and Sn up to 3.6 % (analysis 16).

Kotulskite (Pd,Au)Te

Description

Kotulskite (Pd,Au)Te as well as Pd-arsenides spatially relate to the grains of gold alloys. Kotulskite isfound in 10 particles and constitute 0.8 area % of all precios metal minerals. Kotulskite occurs at the margin of gold alloy grains (Plates 10, #*1-10*) and sometimes together with Pd-arsenides (Plate 10, #*7-9*). Kotulskite is as other PGMs and Au-alloys very often associated to bornite and chalcopyrite (Plate 10, #*4-10*) sometimes to rock-forming pyroxenes, ilmenite and chlorite (Plate 10, #*8-10*). The kotulskite grains have irregular shapes. Their sizes varies between 2.3 and 10.9 μm with an average of 6.9 μm

Mineral chemistry

Six analyses from 6 different grains constrain the composition of kotulskite (Table 7, analyses 19-24; the average analysis 25). The typical substitution in kotulskite is Au with up to 6.2 wt% (Table 7, analysis 21).

Vysotskite PdS

Vysotskite comprise 1.0 area % of all precious metal minerals. One 26 μm liberated grain of vysotskite has been located in the HS concentrates (Plate 10, #*11*). It´s compositions is closed to stoichiometric PdS (Plate 7, analysis 28).

Sperrylite $PtAs_2$

Just one small inclusion of sperrylite was found in a grain of (Au,Cu,Ag) alloy (Plate 9, #14: Table 7, analysis 26). The sperrylite grain is ca. 6 μm in size and constitute 0.1 area % of all precious metal phases.

Hessite Ag_2Te

One intergrowth of hessite and chalcopyrite was found in the HS-concentrate (Plate10, #*12*: Table 7, analysis 27). The hessite grain has an irregular form and is ~10 mm in size, equivalent to ca 0.1 area % of all precious metal phases)

Native silver (Au,Cu)

One larger, irregular grain (EDC = 58.3 μm in size, 5.2 area % of all precious metal minerals grains) of native silver (Ag,Cu) was found (Plate 10, #*13*; Table 6, analysis 79) in the HS-concentrates. Substitution of Ag by Cu amounts to Cu 6.7 wt.% (Table 6).

Atokite Pd_3Sn

Small inclusions (~3 μm) of atokite were only identified by their X-ray spectrum on the micro-probe. They occur as inclusions or exsolutions in one of the grains of (Au,Cu,Ag) alloy (Plate 9, #*18*).

Discussion

Bornite and chalcopyrite constitute ~98 % of the sulphide paragenesis in sample 90-10 434. Bornite and chalcopyrite grains and their aggregates form characteristic droplet-like micro-globules (see Plate 3, #*1-4*; Plate 4, # *1-3* etc). The characteristic exsolutions textures with chalcopyrite lamelli in a bornite are shown in Plate 4 (#*1, 4-11*).

(Au,Cu,Ag,Pd) alloys dominate the precious metal mineralisation (Table 3). (Au,Cu,Ag,Pd) alloys, as a rule, are Au-rich, sometimes with Ag (up to (Au,Ag) alloy but are poor in Pd and Cu (see Table 6).

Many (Au,Cu,Ag,Pd) alloy grains enclosed in Cu-sulphides, have isometric droplet-like shapes or rounded outlines (Plate 7, # *1-9, 15*: Plate 9, #*9, 11, 12*; Plate 10, #*2* etc.). Irregular grains of (Au,Cu,Ag,Pd) alloy are always associated with rock-forming minerals (see Plate 8). Two (Au,Cu,Ag,Pd) alloy associations are identified:

1) droplet like grains (Plate 6, #*1-4, 7* etc) related to the sulphide association;
2) irregular shaped grains related to crystallization in intercumulus space (Plate 6, #*8-25*).

PGMs represent <10 % of the precious metal paragenesis (Table 3). The PGMs belong to two groups: 1) Pd and Pt arsenides (arsenopalladinite, guanglinite, palladoarsenide and sperrylite); 2) Pd tellurides (kotulskite). Both groups are as a rule localized at the margin of gold alloy grains (see Plates 9 and 10).

The bornite and chalcopyrite paragenesis relate to both the (Au,Cu,Pd) alloys and the PGM paragenesis. All observations of intergrain relations suggest that main part of precious metal minerals forms a single paragenesis with the Cu-Fe sulphides.

Pd-tellurides (kotulskite), and Pd-arsenides (arsenopaslladinite, guanglinite, palladoarsenide and sperrylite) are mostly found at the margins of grains of Au-rich alloy and H_2O-bearing minerals. These observations suggests re-equilibration and replacement at the margins of Au-rich alloys from volatile rich-residual components In the crystallising gabbro.

The Au-Pd mineralisation in sample 90-10 434 is the upper Au ore zone in core 90-10, only located ca. 10m above the main Pd ore zone (Pd5) and near the margin of the intrusion. Fast crystallization and trapping of high concentrations of metal-bearing fluid during crystallization of the ore main explain the complex precious metal mineralogy.

A high volatile content would corroborate with the many bornite-chalcopyrite intergrowths (as opposed to chalcosine-bornite composition in the centre of the intrusion) and the systematic increase in the chalcopyrite proportion from bottom to top in core 90-10 (samples 90-10 445→90-10 443→90-10 434 parts 14-16). An increase in S-activity with height and cooling would lead to increasing chalcopyrite contents.

The precious metals likewise show a stratigraphic evolution. In Pd5 (sample 90-10 445, bottom) is recorded Pd-sulphides (vasilite and vysotskite) and Pd arsenides (guanglinite), in sample 90-10 443 only 2 m above is recorded Pd sulphides (vasilite and vysotskite) and Pd arsenides (guanglinite) and Pd-intermetallides (atokite, keithkonnite, zvyagintsevite) and (Au,Cu,Pd) alloys, poor in Au, rich in Cu and Pd including tetra-auricupride (Au,Pd)Cu, unnamed $(Au,Pd)_3Cu$, and (Au,Pd,Cu) to sample 90-10 434 dominated by (Au,Cu,Ag,Pd) alloys, rich in Au, and poor in Cu and Pd, together with Pd-arsenides (guanglinite, arsenopalladinite, palladoarsenide), Pd-tellurides (kotulskite) and Ag minerals (hessite, native silver).

In the central part of the intrusion (core 90-24): the levels equivalent to the entire mineralisation in core 90-10 are dominated by Pd-intemetallides (skaergaardite, nielsenite etc.) The top of the mineralization in the center is dominated by (Au,Cu,Pd) alloys, poor in Au, rich in Cu and Pd, tetra-auricupride (Au,Pd)Cu, auricupride $(Au,Pd)Cu_3$, skaergaardite and Pd-tellurides (kethconnite, kotulskite, merenskyite).

The Cu-Fe sulphide droplets in cumulus as well as intercumulus space shows that the formation of sulphide melt took place from an early stage in the solidification of gabbro. The enrichment in Au, Ag, etc.) may reflect second stage enrichment from residual volatiles rich fluids in interstitial space in the almost solidified gabbro.

Taking in consideration sharp irregular form of (Au,Cu,Ag,Pd) alloys possibly reflects the shaping of sulphide droplets by the crystallization of the silicate and FeTi-oxide host or alternatively represent reaction and replacement at grain boundaries in the gabbro.

Summary

1. Sample 90-10 434 (0.703 kg) was investigated using HS heavy mineral concentrates. For detailed investigation was selected 89 grains of precious metal phases, believed to be representative. The precious metal minerals divide in 2 groups: 1) (Au,Cu,Ag,Pd) alloy – a) (Au,Cu,Ag) alloy (83.3 %), b) (Au,Cu,Pd) alloy (1.4 %), c) (Au,Ag,Cu) alloy (2.8 %), and d) (Ag,Cu) alloy (5.2 %); and 2) PGMs (arsenopalladinite, guanglinite, palladoarsenide, sperrylite, kotulskite, vysotskite, atokite – 7.2 % at all) and hessite (0.1 %). The grain size of precious metal minerals as measured by the ECD varies between 6.2 and 58.3 μm with an average of 26 μm.

2. Bornite and chalcopyrite dominate (~98 %) the sulphide paragenesis of the studied gabbro The terms of number of grains bornite-chalcopyrite and chalcopyrite grains represent ~40 % of all grains of base metal sulphides. Bornite and chalcopyrite grains form characteristic droplet like microglobules as well as irregular-shaped particles. The bornite-chalcopyrite grains have characteristic exsolution texture of chalcopyrite which may be explained by their high-temperature primary nature. Cu-Fe sulphide droplets in cumulus as well as intercumulus space of the gabbro strongly suggests the formation of sulphide melt during the early stages of crystallization of these rocks.

3. Many (Au,Cu,Ag,Pd) alloy grains, included in sulphide matrix have isometric droplet-like shape or rounded outlines whereas the same alloy in the matrix of the host gabbro have irregular grain forms

4. Both PGE-arsenides as well as PGE-tellurides are usually localized at the margin of gold alloy grains.

5. The base metal sulphides paragenesis (bornite and chalcopyrite) and (Au,Cu,Pd) alloys and most of the PGMs seem to form one paragenesis.

6. Observations could suggest replacement of Au and Ag as the result of reaction between already formed Cu-sulphide droplets and interstitial fluid or volatile-rich melt which was the source for the Te and As. Au-Pd mineralisation in sample 90-10 434 is the uppermost mineralized level in core 90-10 only some 10m above the basal Pd5 level. The general increase in trapped liquid toward the margin suggest a less permeable crystallization environment and the trapping of volatile phases, the reaction with which is clearly observable in the occurrence of hydreous host rock minerals such as ferrosaponite.

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Appendix: List of abbreviations

Abbreviations used in Figures, Tables and in the text of report

Rock-forming minerals

pl – plagioclase
cpx – monoclinic pyroxene
opx – orthorhombic pyroxene
ilm - ilmenite
timt – titaniferous magnetite
chl – chlorite
q – quartz
pyr (exs) – exsolution texture of monoclinic and orthorhombic pyroxenes

Sulphides

bn - bornite
cp – chalcopyrite
pn – pentlandite
po –pyrrhotite
tet – tetrahedrite
gdm – gudmundite
cls – clausthalite

Precious metal minerals

aspd – arsenopalladinite
gng – guanglinite
plas – palladoarsenide
vys – vysotskite
kt – kotulskite
sp – sperrylite
at – atokite
hs – hessite
(Au,Cu) – alloys of Au and Cu
(Au,Cu,Ag) - alloys of Au, Cu and Ag
(Au,Cu,Ag,Pd) - alloys of Au, Cu, Ag and Pd
(Au,Ag) – alloys Au and Ag
(Au,Cu,Pd) – alloys of Au, Cu and Pd
(Ag,Cu) – alloy of Ag and Cu (native silver)

Mineral associations

L - completely liberated (free) particles of precious metal minerals
Lp - two or more precious metal minerals completely liberated (free) particles
bms – intergrowths of precious metal minerals with base metal sulphides
bms-L - liberated particles of precious metal minerals with <10 % attached base metal sulphides
sag - sulphide and gangue attached to precious metal minerals
sag-L - sulphide and gangue attached to precious metal minerals, but < 10 %
ag – precious metal minerals attached to gangue
ag-L – precious metal minerals attached to gangue, but <10 %.

TABLES

Table 1. Chemical composition and formulas of silicates and oxides of oxide-rich tholeiitic gabbros, sample 90-10 434

	Plagioclase				Clinopyroxen				Low-Ca pyroxene				Titanomagnetite						Ilmenite				
Composition (wt%)																							
An. #	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**9**	**11**	**12**	**13**	**14**	**16**	**17**	**18**	**19**	**20**	**21**	**23**	**24**	**25**	**26**	**27**
SiO_2	55.7	56.3	55.9	56.6	51.3	50.8	50.9	50.6	50.9	50.8	50.8	50.6	-	-	-	-	-	-	-	-	-	-	-
TiO_2	-	-	-	-	0.4	0.5	0.6	0.6	-	-	0.4	0.3	14.1	4.3	3.9	5.7	9.2	13.9	49.1	49.9	50.4	49.3	49.0
Al_2O_3	27.5	27.5	27.3	27.2	1.3	1.5	1.6	1.5	0.7	0.9	0.7	0.6	2.9	3.8	3.3	2.1	1.9	3.0	-	-	-	-	-
V_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	1.2	2.0	1.6	1.2	1.2	1.1	0.5	-	0.4	0.4	0.4
Fe_2O_3	0.3	0.4	0.4	0.4	-	-	-	-	-	-	-	-	37.4	54.1	56.3	56.1	47.5	37.6	7.6	6.3	5.5	6.9	7.6
FeO	-	-	-	-	15.2	15.8	15.4	15.1	29.8	27.3	30.0	28.2	44.8	34.4	33.6	35.7	37.9	43.0	39.3	40.6	41.9	40.5	40.3
MnO	-	-	-	-	0.4	0.3	0.4	0.3	0.6	0.7	0.7	0.7	-	-	-	-	-	0.4	0.4	0.5	0.7	0.6	0.7
MgO	-	-	-	-	13.1	13.5	12.2	13.1	16.2	16.2	16.6	15.6	-	-	1.1	-	-	0.7	2.5	2.2	1.6	1.9	1.7
CaO	9.5	9.4	9.3	9.3	17.8	17.9	18.6	17.9	1.5	3.3	1.4	3.0	-	-	-	-	-	-	-	-	-	-	-
Na_2O	6.1	6.0	6.2	6.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K_2O	0.4	0.4	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
sum	99.5	100.0	99.6	100.1	99.5	100.3	99.7	99.1	99.6	99.2	100.6	99.0	100.3	99.4	99.8	100.7	99.6	99.7	99.4	99.5	100.5	99.4	99.6
Cation proportions																							
Si	2.520	2.530	2.530	2.540	1.960	1.930	1.950	1.940	1.980	1.980	1.960	1.980	-	-	-	-	-	-	-	-	-	-	-
Ti	-	-	-	-	0.010	0.010	0.020	0.020	-	-	0.010	0.010	0.390	0.120	0.110	0.160	0.260	0.390	0.920	0.940	0.940	0.930	0.920
Al	1.470	1.460	1.460	1.440	0.060	0.070	0.070	0.070	0.030	0.040	0.030	0.030	0.130	0.170	0.150	0.090	0.080	0.130	-	-	-	-	-
V	-	-	-	-	-	-	-	-	-	-	-	-	0.040	0.060	0.050	0.040	0.040	0.030	0.010	-	0.010	0.010	0.010
Fe3+	0.010	0.010	0.010	0.010	-	-	-	-	-	-	-	-	1.050	1.530	1.580	1.560	1.360	1.050	0.140	0.120	0.100	0.130	0.140
Fe2+	-	-	-	-	0.480	0.500	0.490	0.480	0.970	0.890	0.910	0.920	1.390	1.080	1.050	1.100	1.200	1.340	0.820	0.850	0.870	0.850	0.850
Fe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.010	0.010	0.010
Mn	-	-	-	-	0.010	0.010	0.010	0.010	0.020	0.020	0.020	0.020	-	-	-	-	-	0.010	0.010	0.010	0.060	0.070	0.060
Mg	-	-	-	-	0.750	0.770	0.700	0.750	0.940	0.940	0.960	0.910	-	-	0.060	-	-	0.040	0.090	0.080	-	-	-
Ca	0.460	0.480	0.450	0.450	0.730	0.730	0.760	0.740	0.060	0.140	0.060	0.130	-	-	-	-	-	-	-	-	-	-	-
Na	0.540	0.520	0.540	0.530	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K	0.020	0.020	0.030	0.030	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum	5.02	5.02	5.02	5.00	4.00	4.02	4.00	4.01	4.00	4.01	3.95	4.00	3.00	2.96	3.00	2.95	2.94	2.99	1.99	2.00	1.99	2.00	1.99
O-basis	8.00	8.00	8.00	8.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	-	-	-	-	-	-	-	-	-	-	-
Cations													3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00
Mg#	-	-	-	-	0.61	0.61	0.59	0.61	0.49	0.51	0.51	0.50	-	-	-	-	-	-	-	-	-	-	-
An%	0.46	0.48	0.45	0.46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. **Chemical composition and formulas of of base metal sulphides, sample 90-10 434**

	Bornite																	
Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19 avr.**
spot/grain	40,#1a	40,#2a	40,#8	40,#21	40,#30a	40-2,#7	2s	3s	8s	11s	13s	14s	16s	19s	22s	29s	30s	wt.%
Analysis																		
Fe	11.0	11.4	11.0		10.5	11.2	11.4	11.4	11.9	11.5	11.9	11.5	11.6	11.5	11.4	11.2	11.6	11.4
Co	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	62.7	62.6	63.5	62.8	62.7	62.7	62.6	62.8	63.1	62.7	63.1	63.3	62.1	62.6	62.4	62.3	62.6	62.7
S	25.5	25.5	25.3	25.6	25.4	25.3	25.6	25.6	25.3	25.7	25.5	25.7	25.4	25.7	25.8	25.6	25.3	25.5
sum	99.2	99.5	99.8	99.7	98.6	99.2	99.6	99.8	100.3	99.9	100.5	100.5	99.1	99.8	99.6	99.1	99.5	99.6
Atomic proportions																		
Fe	0.995	1.029	0.992	0.956	0.956	1.015	1.027	1.025	1.033	1.065	1.028	1.051	1.034	1.034	1.025	1.013	1.048	1.028
Co	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	4.986	4.964	5.034	5.017	5.017	4.993	4.956	4.964	4.948	4.962	4.972	4.943	4.944	4.944	4.933	4.953	4.971	4.968
S	4.018	4.007	3.974	4.027	4.027	3.992	4.017	4.010	4.019	3.973	4.000	4.006	4.022	4.022	4.042	4.033	3.981	4.004
sum	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

	Chalcopyrite									Pentlandite			Pyrrho-tite
Analysis	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**avr.**	**29**	**30**	**31 avr.**	**32**
spot/grain	40-2,#7	10s	13s	15s	23s	25s	28s	29s		100,#1a	1s	wt.%	17s, wt.%
Analysis													
Fe	29.5	30.8	29.7	29.8	31.0	30.9	30.2	30.0	30.2	30.8	30.7	30.8	60.4
Co	-	-	-	-	-	-	-	-		0.7	0.7	0.7	-
Ni	-	-	-	-	-	-	-	-		35.1	35.6	35.4	0.4
Cu	35.5	34.0	35.8	34.5	33.8	33.9	34.4	35.0	34.6	-	-	-	-
S	34.6	34.8	34.4	34.8	35.0	34.8	34.8	34.6	34.7	32.8	33.2	33.0	39.7
sum	99.6	99.6	99.9	99.1	99.8	99.6	99.4	99.6	99.5	99.4	100.2	99.9	100.5
Atomic proportions													
Fe	0.976	1.016	0.981	0.987	1.019	1.019	0.998	0.992	0.999	4.292	4.241	4.270	6.974
Co	-	-	-	-	-	-	-	-	-	0.092	0.092	0.092	
Ni	-	-	-	-	-	-	-	-	-	4.655	4.680	4.670	0.044
Cu	1.032	0.985	1.039	1.005	0.977	0.982	0.999	1.017	1.005	-	-	-	
S	1.993	1.999	1.979	2.008	2.004	1.999	2.003	1.992	1.997	7.960	7.987	7.968	7.982
sum	4	4	4	4	4	4	4	4	4	17	17	17	15

Table 3 **Precious metal minerals of HS-concentrates, sample 90-10 434**

Mineral	General formula	Number of grains	Number of grains	Area	Area	ECD, µm		
			%	μm^2	%	min	avr	max
Alloy	(Au,Cu,Ag)	79	66.4	43028	83.3	9.2	25.1	46.2
Alloy	(Au,Cu,Pd)	2	1.7	704	1.4	6.1	20.7	25.2
Alloy	(Au,Ag,Cu)	3	2.5	1427	2.8	9.7	22.5	34.0
Arsenopalladinite	$(Pd,Cu,Fe,Au)_8As_3$	15	12.6	2119	4.1	7.1	12.8	21.4
Guanglinite	$(Pd,Cu,Fe,Au)_3(As,Sn)$	2	1.7	458	0.9	9.4	15.8	22.2
Palladoarsenide	$(Pd,Pt,Cu,Fe)_2(As,Sn)$	3	2.5	197	0.4	4.4	8.2	13.9
Kotulskite	(Pd,Au)Te	10	8.4	422	0.8	2.3	6.9	10.9
Vysotskite	PdS	1	0.8	532	1.0	-	26	-
Native silver	(Au,Cu)	1	0.8	2665	5.2	-	58.3	-
Sperrylite	$PtAs_2$	1	0.8	30	0.1	-	6.2	-
Atokite	Pd_3Sn	1	0.8	8	0.0	-	3.2	-
Hessite	Ag_2Te	1	0.8	74	0.1	-	9.7	-
Total		119	100.0	51664	100.0			

Table 4. Grain sizes of precious metal minerals, sample 90-10 434

N	Grain#	Association	Type	Mineral	Area, μm2	ECD, μm
1	40,#1	(Au,Cu)-cpx	ag-L	(Au,Cu)	644	28.6
2	40,#2	(Au,Cu)	L	(Au,Cu)	365	21.6
3	40,#3	(Au,Cu)-ilm	ag-L	(Au,Cu)	1277	40.3
4	40,#4	(Au,Cu)-kt-bn-ilm	sag	Total	203	16.1
5	40,#4	(Au,Cu)-kt-bn-ilm	sag	(Au,Cu)	151	13.9
6	40,#4	(Au,Cu)-kt-bn-ilm	sag	kt	52	8.1
7	40,#5	hs-cp	bms	hs	74	9.7
8	40,#6	(Au,Cu)-ilm	ag	(Au,Cu)	774	31.4
9	40,#7	(Au,Ag,Cu)-bn-cpx	sag	(Au,Ag,Cu)	74	9.7
10	40,#8	(Au,Cu)-aspd-bn	bms	Total	491	25.0
11	40,#8	(Au,Cu)-aspd-bn	bms	(Au,Cu)	385	22.1
12	40,#8	(Au,Cu)-aspd-bn	bms	aspd	106	11.6
13	40,#9	(Au,Cu)	L	(Au,Cu)	535	26.1
14	40,#10	(Au,Cu)	L	(Au,Cu)	424	23.2
15	40,#11	(Au,Cu)	L	(Au,Cu)	1063	36.8
16	40,#12	(Au,Cu)	L	(Au,Cu)	427	23.3
17	40,#12-2	(Au,Cu)	L	(Au,Cu)	464	24.3
18	40,#13	(Au,Cu)-bn	bms-L	(Au,Cu)	608	27.8
19	40,#14	(Au,Cu)	L	(Au,Cu)	484	24.8
20	40,#15	(Au,Cu)	L	(Au,Cu)	699	29.8
21	40,#16	(Au,Cu)-gng	Lp	Total	209	16.3
22	40,#16	(Au,Cu)-gng	Lp	(Au,Cu)	139	13.3
23	40,#16	(Au,Cu)-gng	Lp	gng	70	9.4
24	40,#17	(Au,Cu)	L	(Au,Cu)	379	22.0
25	40,#18	(Au,Cu)	L	(Au,Cu)	265	18.4
26	40,#18-2	(Au,Cu)-kt	Lp	Total	705	30.0
27	40,#18-2	(Au,Cu)-kt	Lp	(Au,Cu)	665	29.1
28	40,#18-2	(Au,Cu)-kt	Lp	kt	40	7.1
29	40,#19	vys	L	vys	532	26.0
30	40,#20	(Au,Cu,Pd)-aspd	Lp	Total	386	22.2
31	40,#20	(Au,Cu,Pd)-aspd	Lp	(Au,Cu,Pd)	204	16.1
32	40,#20	(Au,Cu,Pd)-aspd	Lp	aspd	182	15.2
33	40,#21	aspd-(Au,Cu)-bn-cp	bms	Total	277	18.8
34	40,#21	aspd-(Au,Cu)-bn-cp	bms	(Au,Cu)	216	16.6
35	40,#21	aspd-(Au,Cu)-bn-cp	bms	aspd	61	8.8
36	40,#22	(Au,Cu)	L	(Au,Cu)	580	27.2
37	40,#23	(Au,Cu)	L	(Au,Cu)	737	30.6
38	40,#23-2	(Au,Cu)-at	Lp	Total	511	25.5
39	40,#23-2	(Au,Cu)-at	Lp	(Au,Cu)	503	25.3
40	40,#23-2	(Au,Cu)-at	Lp	at	8	3.2
41	40,#24	(Au,Cu)-aspd	Lp	Total	1079	37.1
42	40,#24	(Au,Cu)-aspd	Lp	(Au,Cu)	1006	35.8
43	40,#24	(Au,Cu)-aspd	Lp	aspd	73	9.6
44	40,#25	(Au,Cu)-pyr	ag-L	(Au,Cu)	967	35.1
45	40,#26	(Au,Cu)-kt	Lp	Total	346	21.0
46	40,#26	(Au,Cu)-kt	Lp	(Au,Cu)	342	20.9
47	40,#26	(Au,Cu)-kt	Lp	kt	4	2.3
48	40,#27	aspd-cp	bms	aspd	293	19.3
49	40,#28	(Au,Cu)-pyr	ag-L	(Au,Cu)	459	24.2
50	40,#29	(Au,Cu)-bn-cp	bms	(Au,Cu)	488	24.9
51	40,#30	(Au,Cu,Pd)-aspd	Lp	Total	599	27.6
52	40,#30	(Au,Cu,Pd)-aspd	Lp	(Au,Cu,Pd)	500	25.2

Table 4 continued

N	Grain#	Association	Type	Mineral	Area, µm2	ECD, µm
53	40,#30	(Au,Cu,Pd)-aspd	Lp	aspd	99	11.2
54	40,#31	(Au,Cu)-aspd	Lp	Total	1113	37.7
55	40,#31	(Au,Cu)-aspd	Lp	(Au,Cu)	1005	35.8
56	40,#31	(Au,Cu)-aspd	Lp	aspd	108	11.7
57	40,#32	(Au,Cu)	L	(Au,Cu)	81	10.2
58	40,#33	(Au,Cu)	L	(Au,Cu)	140	13.4
59	40,#34	(Au,Cu)-pyr	ag	(Au,Cu)	294	19.4
60	40,#35	(Au,Cu)-aspd	Lp	Total	1032	36.3
61	40,#35	(Au,Cu)-aspd	Lp	(Au,Cu)	838	32.7
62	40,#35	(Au,Cu)-aspd	Lp	aspd	194	15.7
63	40,#36	(Au,Cu)-ilm	ag-L	(Au,Cu)	390	22.3
64	40,#37	(Au,Cu)-ilm	ag	(Au,Cu)	162	14.4
65	40,#37-2	Ag	L	Ag	2665	58.3
66	40-2,#1	(Au,Cu)-gng-plas-cp-chl	sag-L	Total	484	24.8
67	40-2,#1	(Au,Cu)-gng-plas-cp-chl	sag-L	(Au,Cu)	66	9.2
68	40-2,#1	(Au,Cu)-gng-plas-cp-chl	sag-L	gng	388	22.2
69	40-2,#1	(Au,Cu)-gng-plas-cp-chl	sag-L	plas	30	6.2
70	40-2,#2	(Au,Cu)	L	(Au,Cu)	358	21.4
71	40-2,#3	(Au,Cu)-cp	bms-L	(Au,Cu)	293	19.3
72	40-2,#4	(Au,Cu)	L	(Au,Cu)	421	23.2
73	40-2,#5	(Au,Cu)-kt	Lp	Total	1310	40.9
74	40-2,#5	(Au,Cu)-kt	Lp	(Au,Cu)	1235	39.7
75	40-2,#5	(Au,Cu)-kt	Lp	kt	75	9.8
76	40-2,#6	(Au,Cu)-bn	bms-L	(Au,Cu)	346	21.0
77	40-2,#7	(Au,Cu)-bn-cp	bms	(Au,Cu)	190	15.6
78	40-2,#8	(Au,Cu)-bn	bms-L	(Au,Cu)	738	30.7
79	40-2,#9	(Au,Cu)-aspd-bn-cp	bms-L	Total	999	35.7
80	40-2,#9	(Au,Cu)-aspd-bn-cp	bms-L	(Au,Cu)	932	34.5
81	40-2,#9	(Au,Cu)-aspd-bn-cp	bms-L	aspd	67	9.2
82	40-2,#10	(Au,Cu)-bn-chl	sag	(Au,Cu)	189	15.5
83	40-2,#11	(Au,Cu)-bn-cp	bms	(Au,Cu)	454	24.0
84	40-2,#12	(Au,Cu)-bn	bms	(Au,Cu)	1675	46.2
85	40-2,#13	(Au,Cu)	L	(Au,Cu)	619	28.1
86	40-2,#14	(Au,Cu)	L	(Au,Cu)	372	21.8
87	40-2,#15	(Au,Cu)	L	(Au,Cu)	545	26.3
88	40-2,#16	(Au,Cu)-kt-bn	bms	Total	277	18.8
89	40-2,#16	(Au,Cu)-kt-bn	bms	(Au,Cu)	226	17.0
90	40-2,#16	(Au,Cu)-kt-bn	bms	kt	51	8.1
91	40-2,#17	(Au,Cu)-bn	bms-L	(Au,Cu)	342	20.9
92	40-2,#18	(Au,Cu)	L	(Au,Cu)	543	26.3
93	40-2,#19	(Au,Cu)-plas	Lp	Total	710	30.1
94	40-2,#19	(Au,Cu)-plas	Lp	(Au,Cu)	558	26.7
95	40-2,#19	(Au,Cu)-plas	Lp	plas	152	13.9
96	40-2,#20	(Au,Cu)-aspd	Lp	Total	219	16.7
97	40-2,#20	(Au,Cu)-aspd	Lp	(Au,Cu)	133	13.0
98	40-2,#20	(Au,Cu)-aspd	Lp	aspd	86	10.5
99	40-2,#21	(Au,Cu)	L	(Au,Cu)	302	19.6
100	40-2,#22	(Au,Cu)-sp	Lp	Total	435	23.5
101	40-2,#22	(Au,Cu)-sp	Lp	(Au,Cu)	405	22.7
102	40-2,#22	(Au,Cu)-sp	Lp	sp	30	6.2
103	40-2,#23	(Au,Cu)-kt-bn	bms-L	Total	979	35.3
104	40-2,#23	(Au,Cu)-kt-bn	bms-L	(Au,Cu)	949	34.8

Table 4 continued

N	Grain#	Association	Type	Mineral	Area, μm2	ECD, μm
105	40-2,#23	(Au,Cu)-kt-bn	bms-L	kt	30	6.2
106	40-2,#24	(Au,Cu)-kt	Lp	Total	874	33.4
107	40-2,#24	(Au,Cu)-kt	Lp	(Au,Cu)	781	31.5
108	40-2,#24	(Au,Cu)-kt	Lp	kt	93	10.9
109	40-2,#25	(Au,Cu)-aspd-kt	Lp	Total	443	23.8
110	40-2,#25	(Au,Cu)-aspd-kt	Lp	(Au,Cu)	317	20.1
111	40-2,#25	(Au,Cu)-aspd-kt	Lp	aspd	119	12.3
112	40-2,#25	(Au,Cu)-aspd-kt	Lp	kt	7	3.0
113	40-2,#26	(Au,Cu)-bn	bms-L	(Au,Cu)	1026	36.2
114	40-2,#27	(Au,Cu)-cp	bms-L	(Au,Cu)	445	23.8
115	40-2,#28	(Au,Cu)	L	(Au,Cu)	290	19.2
116	40-2,#29	(Au,Cu)-bn	bms	(Au,Cu)	505	25.4
117	40-2,#30	(Au,Cu)	L	(Au,Cu)	918	34.2
118	40-2,#31	(Au,Ag,Cu)-aspd	Lp	Total	1022	36.1
119	40-2,#31	(Au,Ag,Cu)-aspd	Lp	(Au,Ag,Cu)	909	34.0
120	40-2,#31	(Au,Ag,Cu)-aspd	Lp	aspd	113	12.0
121	40-2,#32	(Au,Cu)	L	(Au,Cu)	505	25.4
122	40-2,#33	(Au,Cu)-aspd	Lp	Total	460	24.2
123	40-2,#33	(Au,Cu)-aspd	Lp	(Au,Cu)	101	11.3
124	40-2,#33	(Au,Cu)-aspd	Lp	aspd	360	21.4
125	40-2,#34	(Au,Cu)	L	(Au,Cu)	722	30.3
126	70,#1	(Au,Cu)	L	(Au,Cu)	104	11.5
127	70,#2	(Au,Cu)-cp-pyr	sag	(Au,Cu)	548	26.4
128	70,#3	(Au,Cu)-pl	ag	(Au,Cu)	367	21.6
129	70,#4	(Au,Cu)-cp-bn-chl	sag	(Au,Cu)	290	19.2
130	70,#5	(Au,Cu)-aspd-bn-pyr	sag	Total	741	30.7
131	70,#5	(Au,Cu)-aspd	Lp	(Au,Cu)	701	29.9
132	70,#5	(Au,Cu)-aspd	Lp	aspd	40	7.1
133	70,#6	(Au,Cu)-bn-opx	sag	(Au,Cu)	1375	41.9
134	70-2,#1	(Au,Cu)-kt-bn-cp-cpx	sag	Total	358	21.4
135	70-2,#1	(Au,Cu)-kt-bn-cp-cpx	sag	(Au,Cu)	316	20.1
136	70-2,#1	(Au,Cu)-kt-bn-cp-cpx	sag	kt	42	7.3
137	70-2,#2	(Au,Ag,Cu)	L	(Au,Ag,Cu)	444	23.8
138	70-2,#3	(Au,Cu)-bn	bms-L	(Au,Cu)	1276	40.3
139	70-2,#4	(Au,Cu)-cp-chl	sag	(Au,Cu)	587	27.3
140	70-2,#5	(Au,Cu)-cp-chl	sag	(Au,Cu)	740	30.7
141	100,#1	(Au,Cu)-aspd-plas-kt-cp-chl	sag	Total	1295	40.6
142	100,#1	(Au,Cu)-aspd-plas-kt-cp-chl	sag	(Au,Cu)	1034	36.3
143	100,#1	(Au,Cu)-aspd-plas-kt-cp-chl	sag	aspd	218	16.7
144	100,#1	(Au,Cu)-aspd-plas-kt-cp-chl	sag	plas	15	4.4
145	100,#1	(Au,Cu)-aspd-plas-kt-cp-chl	sag	kt	28	6.0
146	100,#2	(Au,Cu)-cp-bn-pyr	sag	(Au,Cu)	233	17.2

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy.
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite;at:atokite; plas: palladoarsenite; sp: sperrylite.
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite.
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite.

Table 5. Mineral associations of different groups of precious metal minerals by grains, sample 90-10 434

Association	Number of grains	Number of grains (%)	Area, μm^2	Area% %	ECD, µm		
					min	average	max
L	29	32.6	15983	30.9	10.2	25.1	58.3
Lp	17	19.1	11453	22.2	16.3	28.4	40.9
bms	10	11.2	4724	9.1	9.7	22.8	46.2
bms-L	10	11.2	7052	13.6	19.3	29.1	40.3
sag	12	13.5	6633	12.8	9.7	24.7	41.9
sag-L	2	2.2	514	1.0	6.2	15.5	24.8
ag	4	4.5	1597	3.1	14.4	21.7	31.4
ag-L	5	5.6	3737	7.2	22.3	30.1	40.3
Total	89	100.0	51693	100.0			

Table 6. Chemical composition and formulas of Au-Cu-Ag alloys, HS-oncentrates of sample 90-10 434

	(Au,Cu,Ag) alloy											
Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
grain/point #	40,#1	40,#2	40,#3	40,#4	40,#6	40,#8	40,#9	40,#10	40,#11	40,#12	40,#13	40,#14
Association	(Au,Cu,Ag) +cpx	(Au,Cu,Ag)	(Au,Cu,Ag) +ilm	(Au,Cu,Ag) +kt+bn +ilm	(Au,Cu,Ag) +ilm	(Au,Cu,Ag) +aspd+bn	(Au,Cu,Ag)	(Au,Cu,Ag)	(Au,Cu,Ag)	(Au,Cu,Ag)	(Au,Cu,Ag)	(Au,Cu,Ag)
analysis (wt%)												
Cu	3.7	8.3	4.0	5.3	3.9	2.4	4.1	3.8	4.2	4.5	3.4	5.6
Pt	-	-	-	-	-	-	-	-	2.3	-	-	-
Pd	-	-	-	-	-	-	-	-	-	-	-	-
Au	93.2	90.9	93.6	92.0	93.9	94.0	94.3	94.0	93.3	92.5	94.6	92.3
Ag	2.4	0.8	1.7	2.4	1.6	3.4	1.4	1.6	1.3	2.6	1.5	1.4
Total	99.3	100.0	99.3	99.7	99.4	99.8	99.8	99.4	101.1	99.6	99.5	99.3
Proportions (sums to 1)												
Cu	0.105	0.218	0.114	0.146	0.111	0.069	0.116	0.108	0.117	0.125	0.098	0.155
Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Au	0.855	0.770	0.858	0.816	0.862	0.873	0.861	0.865	0.840	0.832	0.877	0.823
Ag	0.040	0.012	0.028	0.039	0.027	0.058	0.023	0.027	0.021	0.043	0.025	0.023

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 6 continued

	(Au,Cu,Ag) alloy											
Analysis	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
grain/point #	40,#15	40,#16	40,#17	40,#21	40,#22	40,#23	40,#24	40,#25	40,#26	40,#28	40,#31	40,#32
Association	(Au,Cu,Ag)	(Au,Cu,Ag) +gng	(Au,Cu,Ag)	(Au,Cu,Ag) +aspd+bn +cp	(Au,Cu,Ag)	(Au,Cu,Ag) +at	(Au,Cu,Ag) +aspd	(Au,Cu,Ag)	(Au,Cu,Ag) +kt	(Au,Cu,Ag)	(Au,Cu,Ag) +aspd	(Au,Cu,Ag)
analysis (wt%)												
Cu	4.9	2.3	4.5	3.2	3.3	4.0	3.2	3.4	5.0	3.6	3.8	3.5
Pt	-	-	-	-	-	-	-	-	-	-	3.6	-
Pd	-	-	-	-	-	-	-	-	-	-	-	-
Au	92.0	93.5	92.7	92.8	93.9	94.0	94.2	93.6	92.5	94.5	90.6	93.9
Ag	2.5	3.8	2.1	3.2	2.2	1.4	2.4	2.7	1.9	1.4	2.0	2.4
Total	99.4	99.6	99.3	99.2	99.4	99.4	99.8	99.7	99.4	99.5	100.0	99.8
Proportions (sums to 1)												
Cu	0.136	0.066	0.126	0.091	0.095	0.114	0.091	0.097	0.139	0.103	0.107	0.099
Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.000
Pd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Au	0.823	0.869	0.839	0.855	0.868	0.863	0.868	0.858	0.830	0.873	0.826	0.860
Ag	0.041	0.065	0.035	0.054	0.037	0.023	0.040	0.045	0.031	0.024	0.033	0.040

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guaganglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 6 continued

Analysis	25	26	27	28	29	30	31	32	33	34	35	36	37
grain/point #	40,#33	40,#35	40,#37	40,#38	40-2,#2	40-2,#3	40-2,#4	40-2,#5	40-2,#5	40-2,#7	40-2,#8	40-2,#9	40-2,#10
Association	(Au,Cu,Ag)	(Au,Cu,Ag) +aspd	(Au,Cu,Ag) +ilm+cp +bn	(Au,Cu,Ag) +ilm	(Au,Cu,Ag)	(Au,Cu,Ag) +cp	(Au,Cu,Ag)	(Au,Cu,Ag) +kt	(Au,Cu,Ag) +bn	(Au,Cu,Ag) +bn+cp	(Au,Cu,Ag) +bn	(Au,Cu,Ag) +aspd+bn +cp	(Au,Cu,Ag) +bn+chl
analysis (wt%)													
Cu	4.3	3.3	2.8	2.6	4.6	3.7	3.6	3.4	2.2	7.3	3.7	4.3	4.4
Pt	-	-	-	-	-	-	-	-	-	-	-	-	-
Pd	-	-	-	-	-	-	-	-	-	-	-	-	-
Au	94.5	93.5	92.9	94.9	93.7	94.7	94.1	94.6	93.7	88.8	94.2	94.3	90.6
Ag	2.0	2.5	3.4	3.1	2.2	2.3	1.8	2.2	5.0	3.4	1.9	1.7	4.2
Total	100.8	99.3	99.1	100.6	100.5	100.7	99.5	100.2	100.3	99.5	99.8	100.3	99.2
Proportions (sums to 1)													
Cu	0.120	0.094	0.081	0.074	0.127	0.104	0.103	0.097	0.062	0.192	0.105	0.120	0.122
Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Au	0.848	0.863	0.862	0.874	0.837	0.858	0.867	0.867	0.855	0.755	0.863	0.852	0.810
Ag	0.033	0.042	0.058	0.052	0.036	0.038	0.030	0.037	0.083	0.053	0.032	0.028	0.069

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 6 continued

Analysis	38	39	40	41	42	43	44	45	46	47	48	49
grain/point #	40-2,#11	40-2,#12	40-2,#13	40-2,#14	40-2,#15	40-2,#16	40-2,#17	40-2,#18	40-2,#19	40-2,#21	40-2,#23	40-2,#24
Association	(Au,Cu,Ag) +bn+cp	(Au,Cu,Ag) +bn	(Au,Cu,Ag) +bn	(Au,Cu,Ag)	(Au,Cu,Ag)	(Au,Cu,Ag) +kt+bn	(Au,Cu,Ag) +bn	(Au,Cu,Ag)	(Au,Cu,Ag) +plas	(Au,Cu,Ag)	(Au,Cu,Ag) +sp	(Au,Cu,Ag) +kt
analysis (wt%)												
Cu	4.2	3.8	3.3	3.1	3.1	6.9	4.6	4.6	2.7	2.4	4.8	3.8
Pt	-	-	-	-	-	-	-	-	2.4	-	-	-
Pd	-	-	-	-	-	-	-	-	-	-	-	-
Au	94.3	94.6	94.7	93.4	95.6	91.6	93.0	92.9	91.3	94.5	93.3	93.5
Ag	1.1	1.1	2.1	3.0	2.1	1.8	1.9	1.8	3.4	3.2	1.4	2.3
Total	99.6	99.5	100.1	99.5	100.8	100.3	99.5	99.3	99.8	100.1	99.5	99.6
Proportions (sums to 1)												
Cu	0.119	0.109	0.094	0.089	0.088	0.184	0.129	0.129	0.077	0.069	0.134	0.108
Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.000
Pd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Au	0.863	0.873	0.871	0.861	0.877	0.788	0.840	0.841	0.843	0.877	0.843	0.854
Ag	0.018	0.019	0.035	0.050	0.035	0.028	0.031	0.030	0.057	0.054	0.023	0.038

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 6 continued

Analysis	50	51	52	53	54	55	56	57	58	59	60	61
grain/point #	40-2,#25	40-2,#26	40-2,#28	40-2,#29	40-2,#30	70,#1	70,#2	70,#3	70,#4	70,#5	70,#6	70-2,#1
Association	(Au,Cu,Ag) +aspd+kt +bn	(Au,Cu,Ag) +bn	(Au,Cu,Ag)	(Au,Cu,Ag) +bn+cp	(Au,Cu,Ag)	(Au,Cu,Ag) +bn	(Au,Cu,Ag) +cp+pyr	(Au,Cu,Ag) +pl	(Au,Cu,Ag) +bn+cp +chl	(Au,Cu,Ag) +aspd+bn +pyr	(Au,Cu,Ag) +bn+opx	(Au,Cu,Ag) +kt+bn+cp
analysis (wt%)												
Cu	5.6	2.6	3.8	5.1	4.4	5.8	3.7	10.6	3.9	5.3	4.9	4.8
Pt	-	-	-	-	-	-	-	-	-	-	-	-
Pd	-	-	-	-	-	-	-	-	-	-	-	-
Au	92.2	93.6	93.3	93.0	92.6	94.1	94.4	86.7	93.8	92.6	92.6	93.8
Ag	1.7	2.9	2.0	1.4	2.2	1.1	1.4	2.2	1.8	1.3	2.2	1.0
Total	99.5	99.1	99.1	99.5	99.1	101.0	99.5	99.5	99.5	99.2	99.7	99.6
Proportions (sums to 1)												
Cu	0.154	0.075	0.108	0.142	0.124	0.158	0.106	0.266	0.111	0.147	0.136	0.135
Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Au	0.818	0.875	0.858	0.835	0.840	0.825	0.871	0.702	0.859	0.831	0.828	0.849
Ag	0.028	0.050	0.034	0.023	0.036	0.018	0.024	0.033	0.030	0.021	0.036	0.017

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 6 continued

						(Au,Cu) alloy				(Au,Ag,Cu) alloy			
Analysis	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**
grain/point #	70-2,#3	70-2,#4	70-2,#5	100,#1	Average	40,#18	40-2,#32	100,#2	Average	40-2,#31	70-2,#2	40,#7	Average
Association	(Au,Cu,Ag) +bn	(Au,Cu,Ag) +cp+chl	(Au,Cu,Ag) +cp+chl	(Au,Cu,Ag) +aspd+plas +kt+cp+chl	wt.%	(Au,Cu) +kt	(Au,Cu)	(Au,Cu) +bn+cp		(Au,Ag) +aspd+bn +cp	(Au,Ag,Cu)	bn+(Au,Ag) +cpx	
analysis (wt%)													
Cu	5.2	4.4	4.3	3.0	4.2	6.7	4.7	5.4	5.6	1.3	2.4	1.4	1.7
Pt	-	-	-	-	-	-	-	-	-	-	-	-	-
Pd	-	-	-	-	-	-	-	-	-	-	-	-	-
Au	93.0	93.6	94.0	92.5	93.2	93.2	94.9	94.0	94.0	85.4	92.0	88.1	88.5
Ag	1.5	1.7	1.2	4.0	2.2	-	-	-	-	13.0	5.6	10.3	9.6
Total	99.7	99.7	99.5	99.5	99.6	99.9	99.6	99.4	99.6	99.7	100.0	99.8	99.8
Proportions (sums to 1)													
Cu	0.144	0.124	0.122	0.085	0.118	0.182	0.133	0.151	0.156	0.036	0.068	0.039	0.047
Pt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Au	0.831	0.848	0.858	0.848	0.845	0.818	0.867	0.849	0.844	0.755	0.839	0.792	0.795
Ag	0.024	0.028	0.020	0.067	0.036	0.000	0.000	0.000	0.000	0.210	0.093	0.169	0.158

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 6 continued

	(Au,Ag) alloy	(Au,Cu,Pd) alloy			(Ag,Cu) alloy
Analysis	**75**	**76**	**77**	**78**	**79**
grain/point #	40-2,#1	40,#20	40,#30	Average	40,#36
Association	(Au,Ag) +gng+plas +cp	(Au,Cu,Pd) +aspd	(Au,Cu,Pd) +aspd		(Ag,Cu)
analysis (wt%)					
Cu	-	3.9	5.1	4.5	6.7
Pt	-	-	-		
Pd	-	3.7	10.3	7.0	
Au	80.1	91.8	84.1	88.0	
Ag	18.9	-	-		92.9
Total	99.0	99.4	99.5	99.5	99.6
Proportions (sums to 1)					
Cu	0.000	0.109	0.133	0.121	0.109
Pt	0.000	0.000	0.000	0.000	0.000
Pd	0.000	0.062	0.160	0.113	0.000
Au	0.699	0.829	0.707	0.766	0.000
Ag	0.301	0.000	0.000	0.000	0.891

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 7: Chemical composition and formulas of platinum group minerals and hessite, HS-concentrates of the sample 90-10 434

	Arsenopalladinite										
Analysis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
point/grain #	40,#8	40,#20	40,#21	40,#27	40,#30	40,#35	40-2,#25	40-2,#31	70,#5	100,#1	
Association	(Au,Cu,Ag)+ aspd+bn	(Au,Cu,Pd) +aspd	(Au,Cu,Ag) +aspd +bn+cp	aspd+cp	(Au,Cu,Pd) +aspd	(Au,Cu,Ag) +aspd	(Au,Cu,Ag) +aspd +kt+bn	(Au,Ag) +aspd +bn+cp	(Au,Cu,Ag) +aspd +bn+pyr	(Au,Cu,Ag)+ aspd+plas +kt+cp +chl	average
Analysi (wt%)											
Fe	0.7	0.6		0.6		0.8	0.5	0.5	0.5	1.2	0.5
Cu	0.7	2.8	2.4	1.2	2.8	2.0	2.7	3.1	3.3	3.0	2.4
S	-	-	-	-	-	-	-	-	-	-	-
Pt	-	-	-	-	-	-	-	-	-	-	-
Pd	77.0	72.6	76.9	76.3	75.3	75.6	74.9	71.4	73.5	74.0	74.8
Au	-	2.1	-	-	-	-	-	3.8	-	-	0.6
Ag	-	-	-	-	-	-	-		-	-	
As	21.0	21.1	21.3	21.0	21.2	21.3	21.4	21.0	21.1	21.5	21.2
Te	-	-	-	-	-	-	-	-	-	-	-
Sn	-	-	-	-	-	-	-	-	-	-	-
sum	99.4	99.2	100.6	99.1	99.3	99.7	99.5	99.8	98.4	99.7	99.5
Atomic proportions											
Fe	0.13	0.12	-	0.11	-	0.16	0.16	0.09	0.10	0.23	0.10
Cu	0.12	0.48	0.40	0.21	0.46	0.33	0.33	0.52	0.55	0.49	0.40
S	-	-	-	-	-	-	-	-	-	-	-
Pt	-	-	-	-	-	-	-	-	-	-	-
Pd	7.75	7.29	7.61	7.67	7.52	7.51	7.51	7.18	7.35	7.28	7.46
Au		0.11	-	-	-	-	-	0.20	-	-	0.03
Ag	-	-	-	-	-	-	-	-	-	-	-
As	3.00	3.01	2.99	3.01	3.01	3.00	3.00	3.00	3.00	3.00	3.00
Te	-	-	-	-	-	-	-	-	-	-	-
Sn	-	-	-	-	-	-	-	-	-	-	-
sum	11	11	11	11	11	11	11	11	11	11	11

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 7 continued

	Guanglinite			Palladoarsenide				Kotulskite				
Analysis	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
point/grain #	40,#16	40-2,#1		40-2,#1	40-2,#19	100,#1		40,#4	40,#18	40-2,#5	40-2,#24	40-2,#25
Association	(Au,Cu,Ag) +gng	(Au,Ag) +gng +plas+cp	average	(Au,Ag) +gng +plas+cp	(Au,Cu,Ag) +plas	(Au,Cu,Ag) +aspd +plas+kt +cp+chl	average	(Au,Cu,Ag) +kt+bn +ilm	(Au,Cu) +kt	(Au,Cu,Ag) +kt	(Au,Cu,Ag) +kt	(Au,Cu,Ag) +aspd +kt+bn
Analysi (wt%)												
Fe	0.9	0.4	0.6	1.0	0.8	0.4	0.7	-	-	-	-	-
Cu	2.5	2.2	2.4	1.8	-	2.9	1.5	-	-	-	-	-
S	-	-	-	-	-	-	-	-	-	-	-	-
Pt	-	-	-	12.4	-	10.9	7.7	-	-	-	-	-
Pd	77.0	75.5	76.3	59.7	72.7	60.0	64.1	45.5	41.5	40.4	45.0	45.6
Au	-	1.6	0.8	-	-	-	-		4.5	6.2	-	-
Ag	-	-	-	-	-	-	-	-	-	-	-	-
As	19.0	18.7	18.9	24.5	23.0	25.1	24.2	-	-	-	-	-
Te	-	-	-	-	-	-	-	54.3	54.1	52.5	54.4	53.3
Sn	-	1.3	0.6	-	3.6	-	1.2	-	-	-	-	-
sum	99.4	99.7	99.6	99.4	99.8	99.3	99.4	99.8	100.1	99.1	99.9	98.9
Atomic proportions												
Fe	0.06	0.04	0.05	0.05	0.03	0.02	0.03	-	-	-	-	-
Cu	0.15	0.14	0.15	0.08	-	0.13	0.07	-	-	-	-	-
S	-	-	-	-	-	-	-	-	-	-	-	-
Pt	-	-	-	0.19	-	0.17	0.12	-	-	-	-	-
Pd	2.80	2.79	2.79	1.69	1.99	1.68	1.79	1.00	0.93	0.92	1.00	1.01
Au	-	0.03	0.01	-	-	-	-	-	0.05	0.08	-	-
Ag	-	-	-	-	-	-	-	-	-	-	-	-
As	0.98	0.98	0.98	0.98	0.89	1.00	0.96	-	-	-	-	-
Te	-	-	-	-	-	-	-	1.00	1.01	1.00	1.00	0.99
Sn	-	0.04	0.02	-	0.09	-	0.03					
sum	4	4	4	3	3	3	3	2	2	2	2	2

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

Table 7 continued

	Kotulskite, continued		Sperry-lite	Hessite	Vysot-skite
Analysis	**24**	**25**	**26**	**27**	**28**
point/grain #	100,#1		40-2,#23	40,#5	40,#19
Association	(Au,Cu,Ag) +aspd +plas+kt +cp+chl	average	(Au,Cu,Ag) +sp	hs+cp	vys
Analysi (wt%)					
Fe	-	-	-	-	-
Cu	-	-	-	-	-
S	-	-	-	-	22.5
Pt	-	-	56.1	-	
Pd	41.1	24.0	-	-	76.8
Au	5.6	2.8	-	-	-
Ag	-	-	-	61.7	-
As	-	-	43.1	-	-
Te	53.1	53.6	-	37.8	-
Sn	-	-	-	-	-
sum	99.8	99.6	99.2	99.5	99.6
Atomic proportions					
Fe	-	-	-	-	-
Cu	-	-	-	-	-
S	-	-	-	-	0.99
Pt	-	-	1.00	-	-
Pd	0.93	0.97	-	-	1.01
Au	0.07	0.03	-	-	-
Ag	-	-	-	1.98	-
As	-	-	2.00	-	-
Te	1.00	1.00	-	1.02	-
Sn			-	-	-
sum	2	2	3	3	2

Abbreviations

Alloys:	(Au,Cu,Ag): alloy; (Au,Cu): alloy; (Au,Ag): alloy; (Au,Ag,Cu): alloy; (Au,Cu.Pd): alloy; (Ag,Cu): alloy
PGMs	Kt: keithconnite; aspd: arsenopalladinite; gng: guanglinite; at: atokite; plas: palladoarsenite; sp: sperrylite
sulphides:	bn: bornite; cp:chalcopyrite; pyr: pyrrhotite
silicates and FeTi-oxides	cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ilm: ilmenite; chl: chlorite;

PLATES

Plate 1

Relationships of rock-forming minerals, Fe-Ti oxides and sulphides in oxide rich tholeiitic gabbros, The sample 90-10, 434 (1-8); polished section, SEM-images (BIE). Abbreviations: cpx: clinopyroxene; opx: orthorhombic pyroxene; pyr (exs): pyroxene exsolutions; pl: plagioclase; q: quartz; timt: titanimagnetite; cp:chalcopyrite.

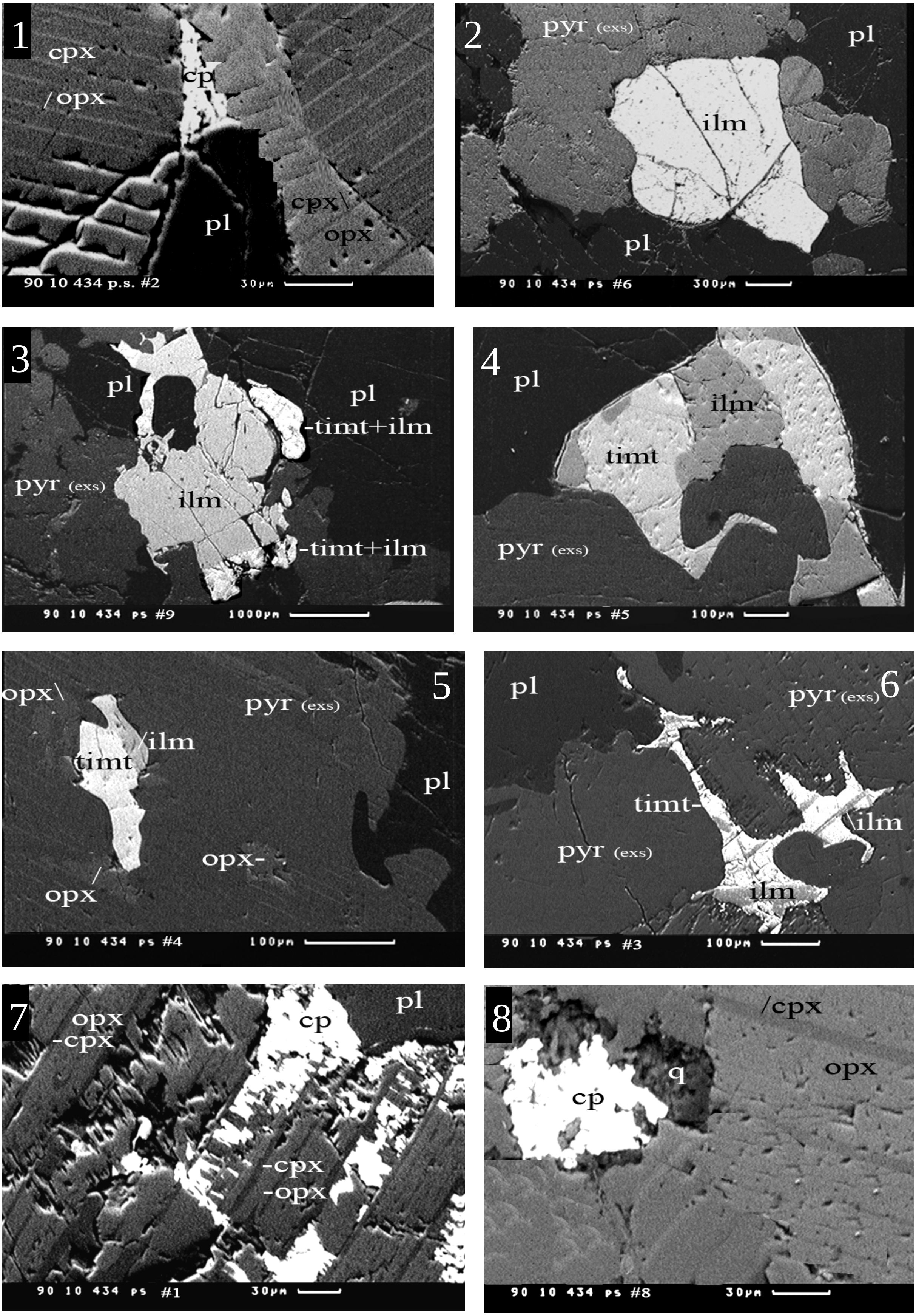
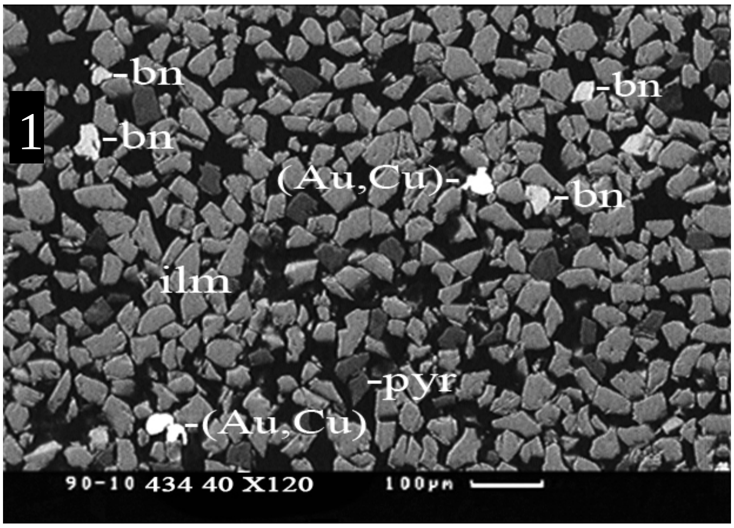
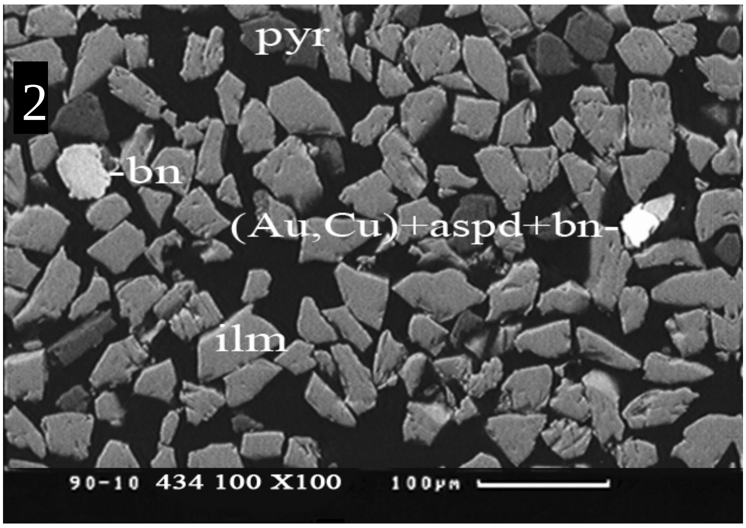

1
cpx
/opx
cp
pl
cpx\
opx
90 10 434 p.s. #2
30μm
2
pyr (exs)
pl
ilm
pl
90 10 434 ps #6
300μm
3
pl
pl
-timt+ilm
pyr (exs)
ilm
-timt+ilm
90 10 434 ps #9
1000μm
4
pl
ilm
timt
pyr (exs)
90 10 434 ps #5
100μm
5
opx\
pyr (exs)
/ilm
timt
pl
opx-
opx
90 10 434 ps #4
100μm
6
pl
pyr (exs)
timt-
\ilm
pyr (exs)
ilm
90 10 434 ps #3
100μm
7
opx
-cpx
cp
pl
-cpx
-opx
90 10 434 ps #1
30μm
8
/cpx
q
cp
opx
90 10 434 ps #8
30μm

Plate 2

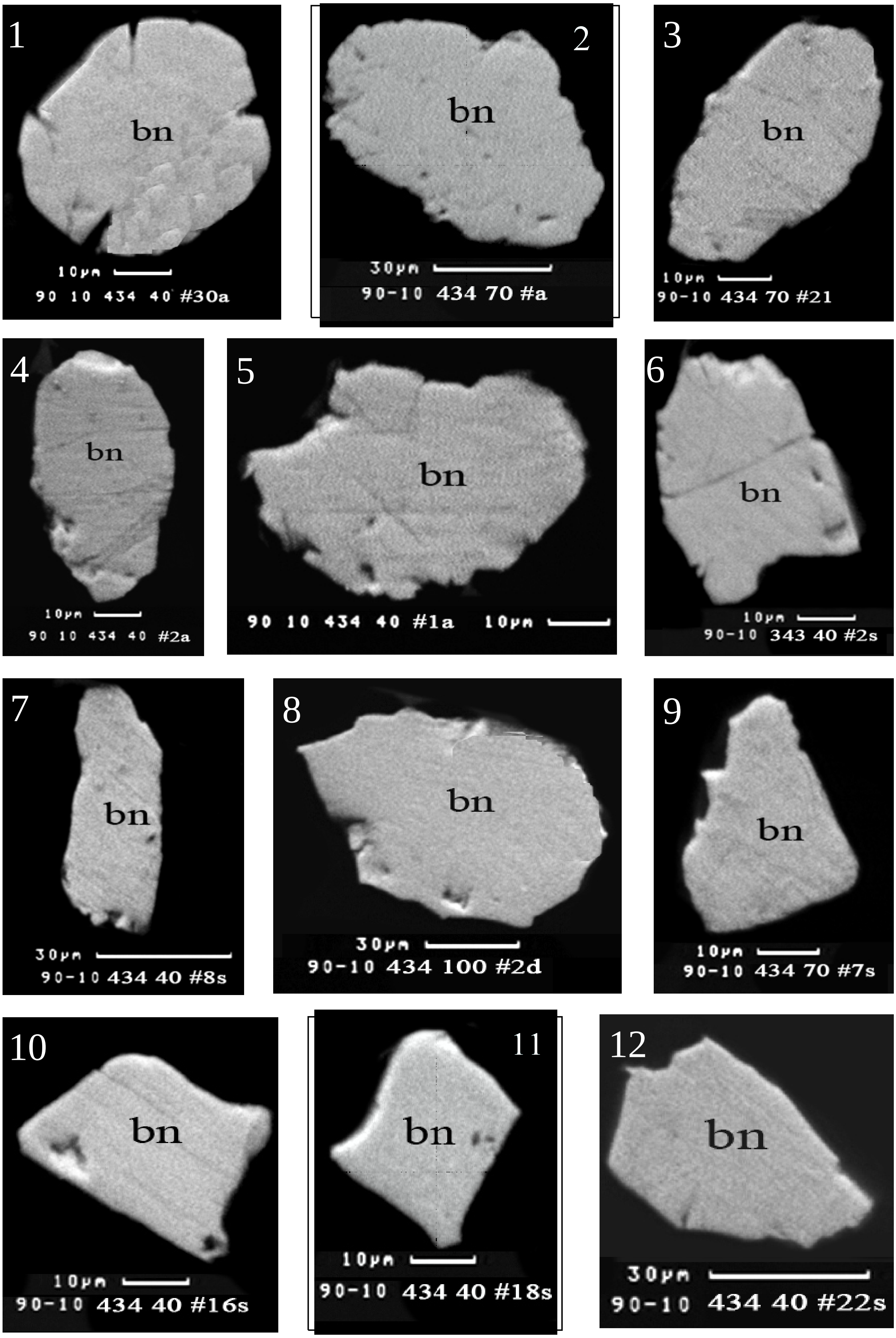




Polished sections of heavy concentrates of sample 90-10 434, SEM-images (BIE):
1) <40 µm fraction, 2) 70-100 µm fraction. Abbreviations: bn: bornite;
(Au,Cu): alloy; ilm: ilmenite, pyr: pyroxene; aspd: arsenopalladinite;

Plate 3

SEM back scatter image of globules and grains of bornite (bn) from oxide-rich tholeiitic gabbro (ilm = ilmenite), sample 90-10 434, grains 1-20 in polished section prepared form heavy mineral concentrate.


1
bn
10μm
90 10 434 40 #30a
2
bn
30μm
90-10 434 70 #a
3
bn
10μm
90-10 434 70 #21
4
bn
10μm
90 10 434 40 #2a
5
bn
90 10 434 40 #1a 10μm
6
bn
10μm
90-10 343 40 #2s
7
bn
30μm
90-10 434 40 #8s
8
bn
30μm
90-10 434 100 #2d
9
bn
10μm
90-10 434 70 #7s
10
bn
10μm
90-10 434 40 #16s
11
bn
10μm
90-10 434 40 #18s
12
bn
30μm
90-10 434 40 #22s

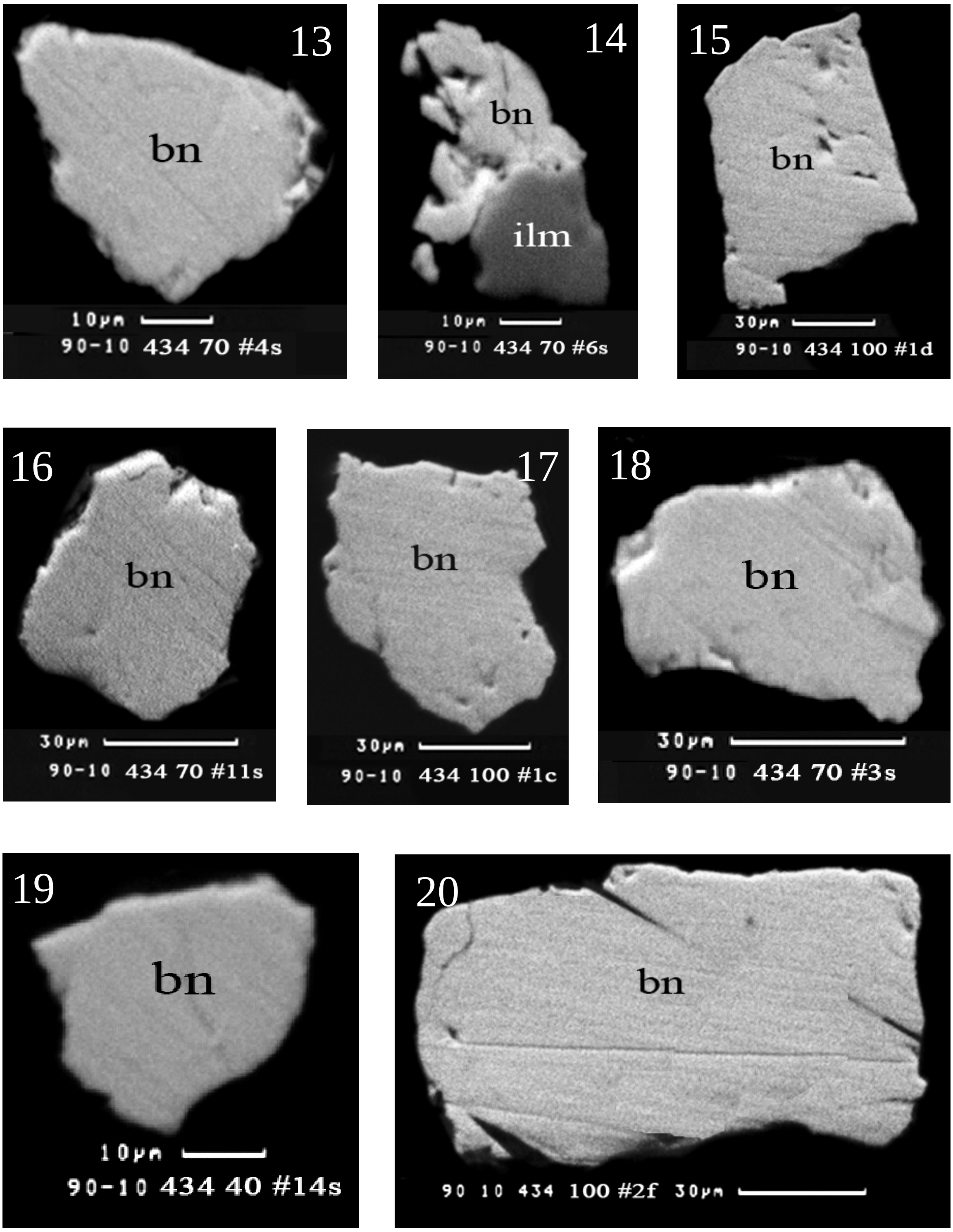
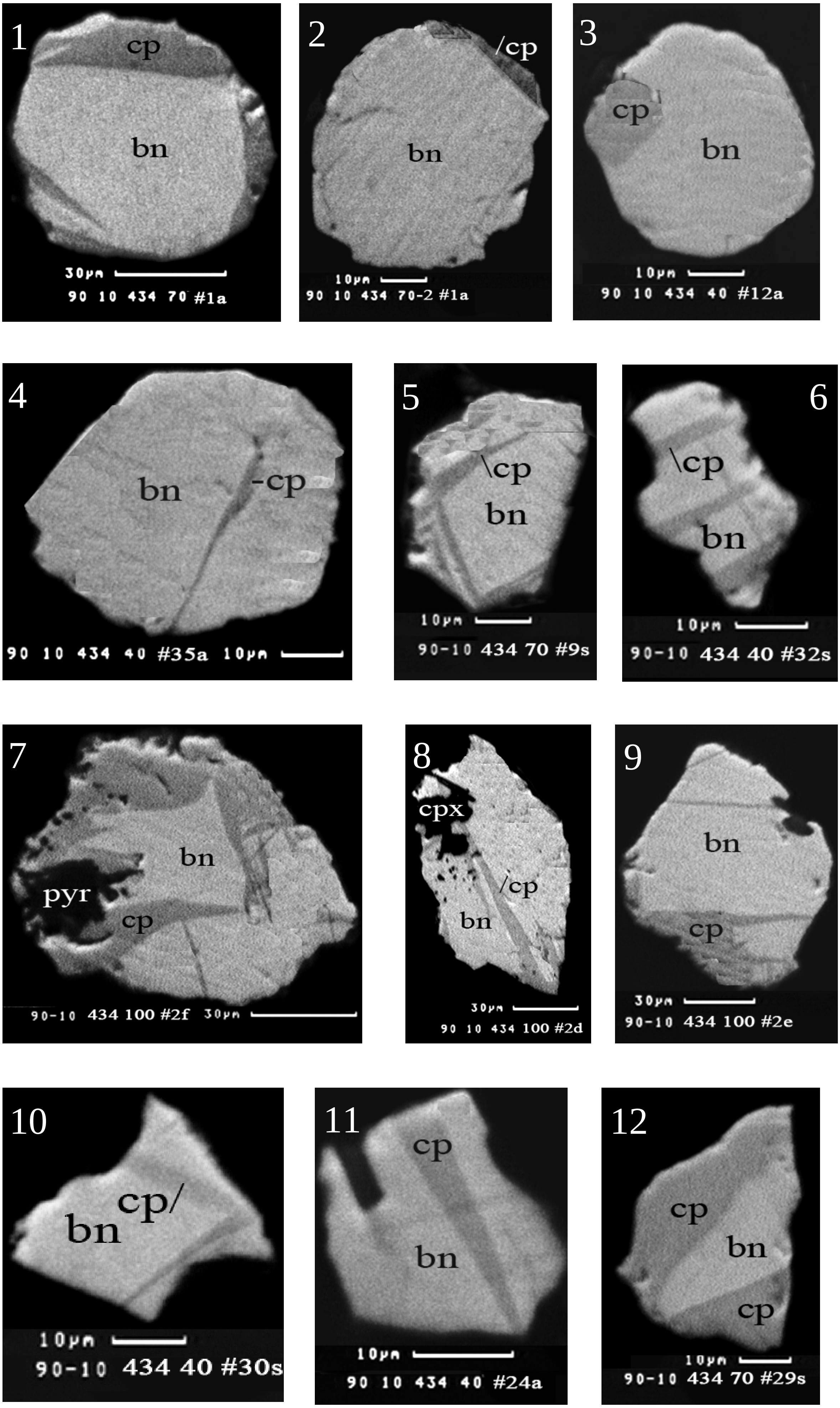

13
bn
10μm
90-10 434 70 #4s
14
bn
ilm
10μm
90-10 434 70 #6s
15
bn
30μm
90-10 434 100 #1d
16
bn
30μm
90-10 434 70 #11s
17
bn
30μm
90-10 434 100 #1c
18
bn
30μm
90-10 434 70 #3s
19
bn
10μm
90-10 434 40 #14s
20
bn
90 10 434 100 #2f 30μm

Plate 4

Cu-sulphide globules and grains (bornite-chalcopyrite and chalcopyrite; 1-19) from oxide-rich tholeiitic gabbros, sample 90-10 434; polished section of grains from HS-concentrates; SEM-images (BIE). Abbreviations: cp: chalcopyrite; bn: bornite; pyr: pyroxene.


1
cp
bn
30µm
90 10 434 70 #1a
2
/cp
bn
10µm
90 10 434 70-2 #1a
3
cp
bn
10µm
90 10 434 40 #12a
4
bn
-cp
90 10 434 40 #35a 10µm
5
\cp
bn
10µm
90-10 434 70 #9s
6
\cp
bn
10µm
90-10 434 40 #32s
7
bn
pyr
cp
90-10 434 100 #2f 30µm
8
cpx
/cp
bn
30µm
90 10 434 100 #2d
9
bn
cp
30µm
90-10 434 100 #2e
10
cp/
bn
10µm
90-10 434 40 #30s
11
cp
bn
10µm
90 10 434 40 #24a
12
cp
bn
cp
10µm
90-10 434 70 #29s

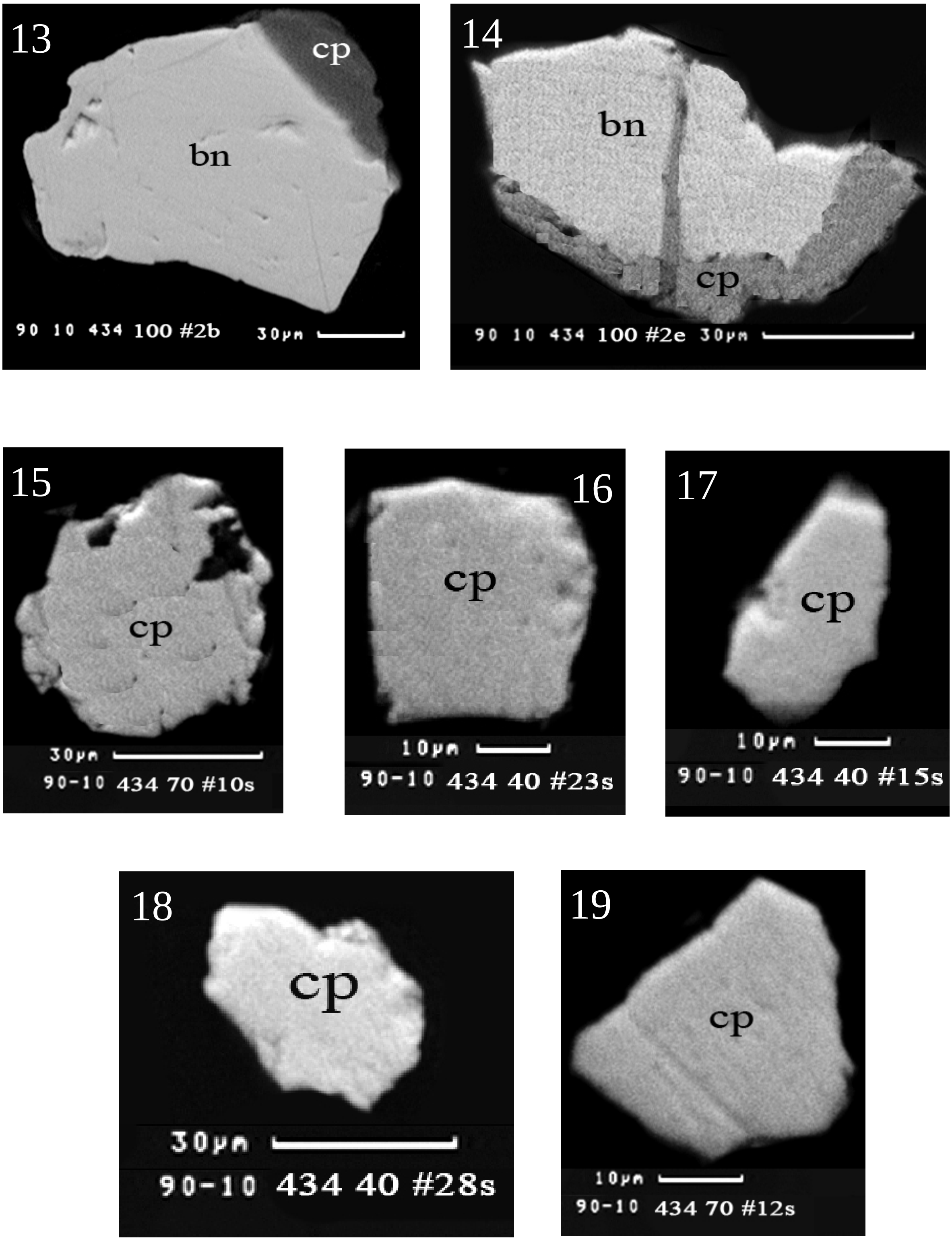
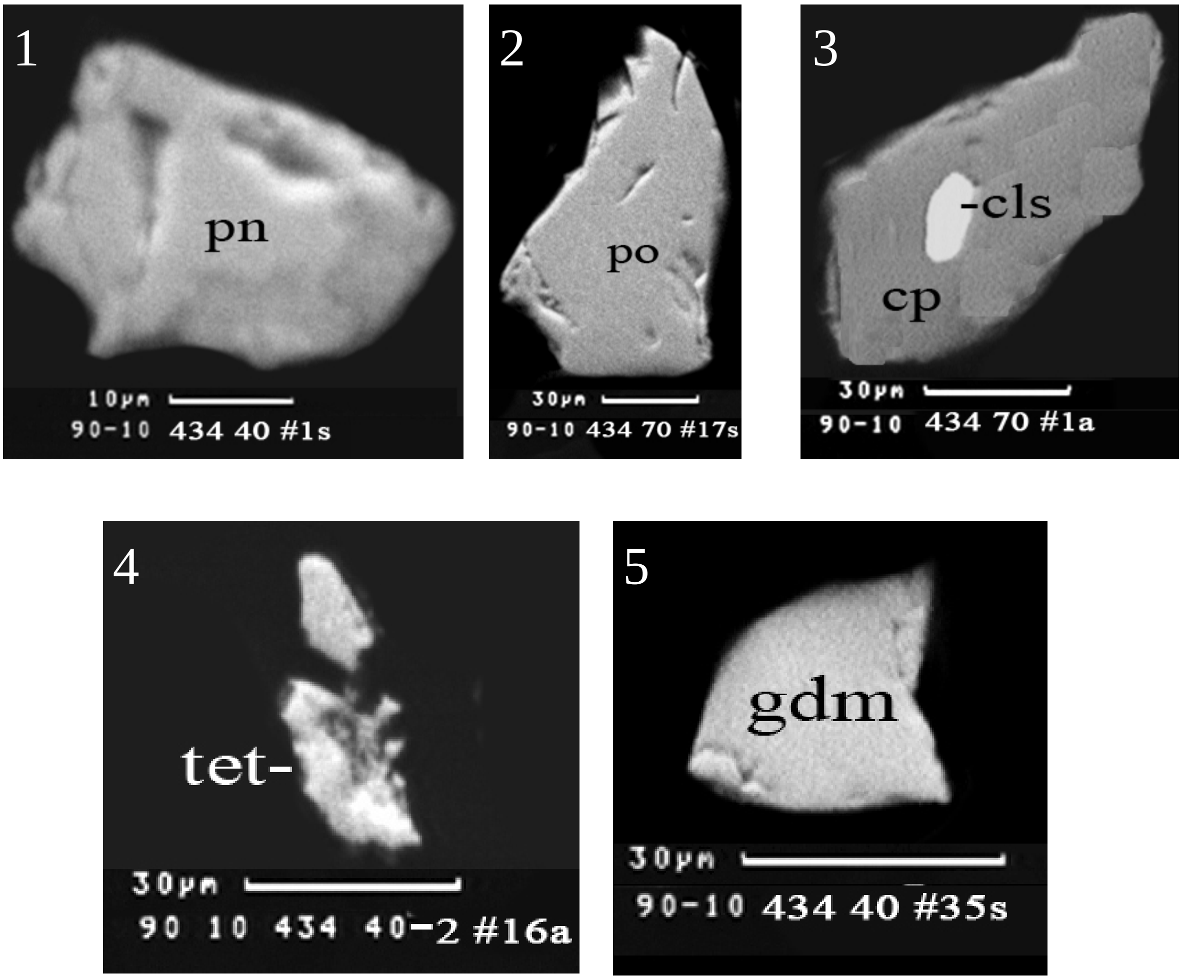

13
cp
bn
90 10 434 100 #2b
30μm
14
bn
cp
90 10 434 100 #2e
30μm
15
cp
30μm
90-10 434 70 #10s
16
cp
10μm
90-10 434 40 #23s
17
cp
10μm
90-10 434 40 #15s
18
cp
30μm
90-10 434 40 #28s
19
cp
10μm
90-10 434 70 #12s

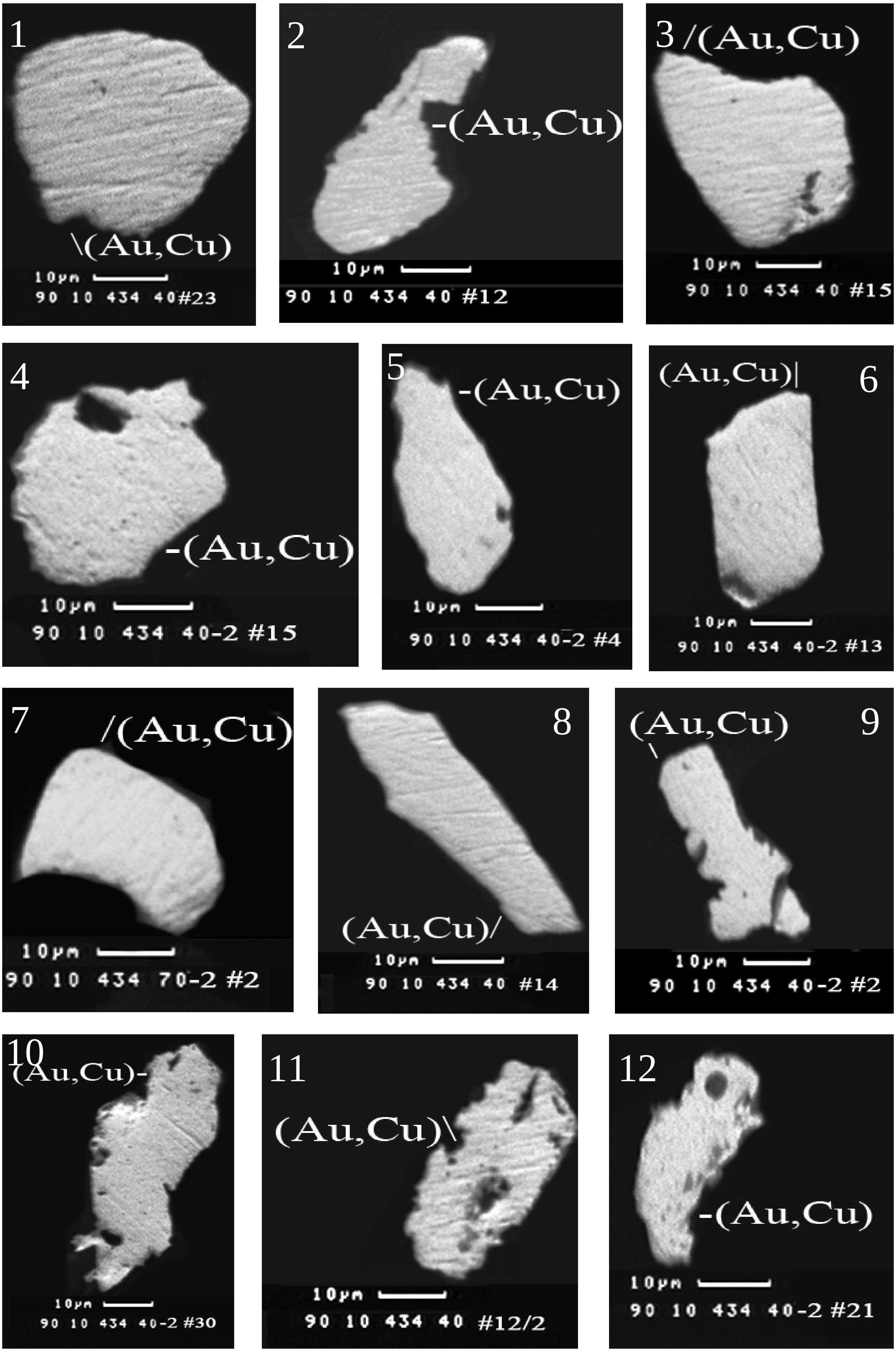
Plate 5



Grains of sulphide mineralization (pn: pentlandite, po: pyrrhotite, cls: clausthalite, tet: tetrahedrite and gdm: gudmundite; 1-5) from oxide-rich tholeiitic gabbros, sample 90-10 434; polished section of grains from HS-concentrates; SEM-images (BIE).

Plate 6

Liberated grains of (Au,Cu,Ag) alloy in heavy mineral HS- concentrates of the sample 90-10 434 (1-25); SEM-images (BIE).


1
\(Au,Cu)
10µm
90 10 434 40#23
2
-(Au,Cu)
10µm
90 10 434 40 #12
3 /(Au,Cu)
10µm
90 10 434 40 #15
4
-(Au,Cu)
10µm
90 10 434 40-2 #15
5
-(Au,Cu)
10µm
90 10 434 40-2 #4
(Au,Cu)|
6
10µm
90 10 434 40-2 #13
7
/(Au,Cu)
10µm
90 10 434 70-2 #2
8
(Au,Cu)/
10µm
90 10 434 40 #14
(Au,Cu)
\
9
10µm
90 10 434 40-2 #2
10
(Au,Cu)-
10µm
90 10 434 40-2 #30
11
(Au,Cu)\
10µm
90 10 434 40 #12/2
12
-(Au,Cu)
10µm
90 10 434 40-2 #21

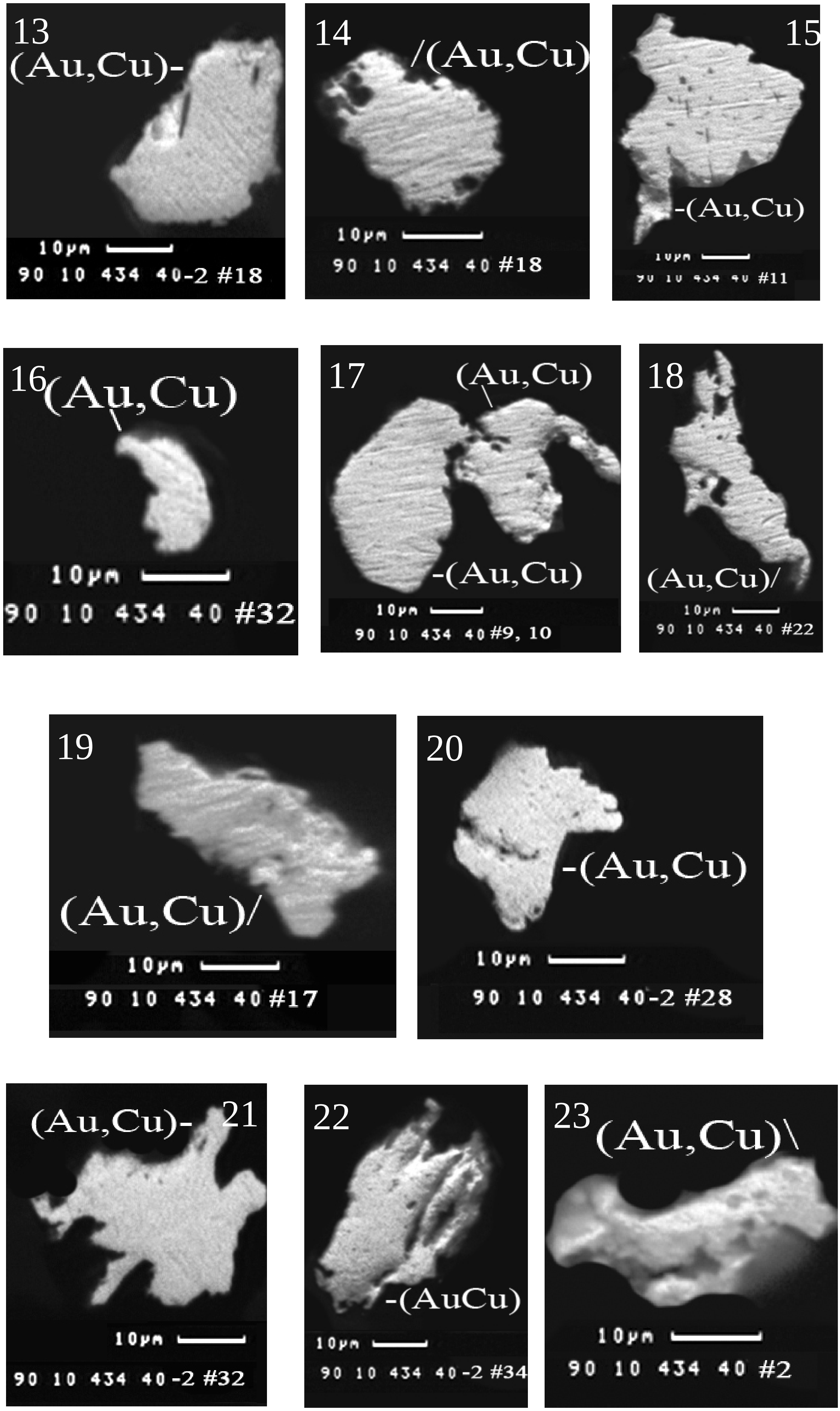
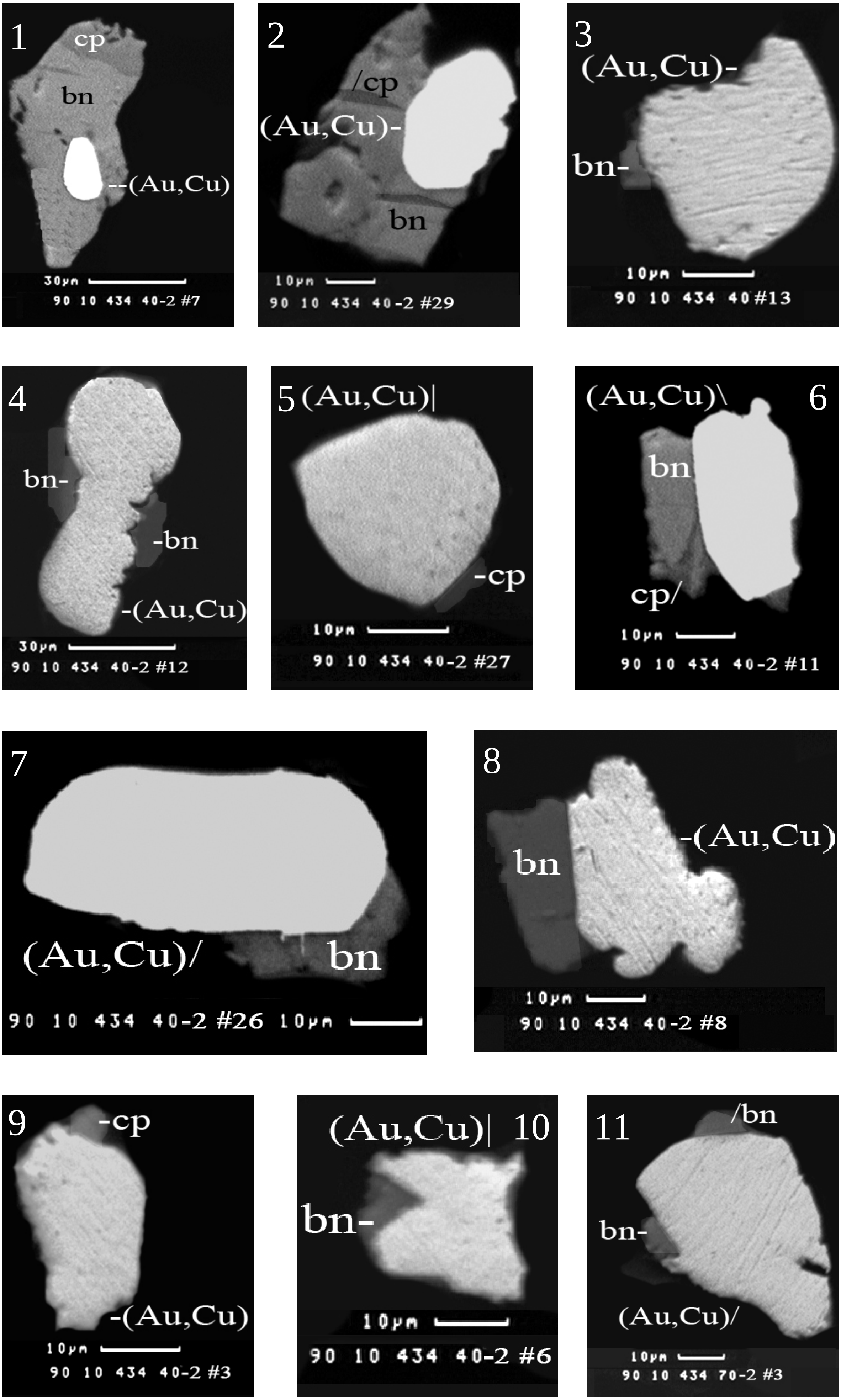

13
(Au,Cu)-
10µm
90 10 434 40-2 #18
14
/(Au,Cu)
10µm
90 10 434 40 #18
15
-(Au,Cu)
90 10 434 40 #11
16
(Au,Cu)
10µm
90 10 434 40 #32
17
(Au,Cu)
-(Au,Cu)
10µm
90 10 434 40 #9, 10
18
(Au,Cu)/
10µm
90 10 434 40 #22
19
(Au,Cu)/
10µm
90 10 434 40 #17
20
-(Au,Cu)
10µm
90 10 434 40-2 #28
21
(Au,Cu)-
10µm
90 10 434 40 -2 #32
22
-(AuCu)
10µm
90 10 434 40 -2 #34
23
(Au,Cu)\
10µm
90 10 434 40 #2

Plate 7

Grains of (Au,Cu,Ag) alloy associated with Cu-Fe sulphides (**bms**, **bms-L**, **sag** associations) from the heavy mineral HS-concentrates of the sample 90-10 434 (grains 1-22); SEM-images (BIE). Abbreviations: cp: chalcopyrite; bn: bornite; pyr: pyroxene; opx: orthopyroxene; cpx: clinopyroxene; chl: chlorite.


1
cp
bn
--(Au,Cu)
30µm
90 10 434 40-2 #7
2
/cp
(Au,Cu)-
bn
10µm
90 10 434 40-2 #29
3
(Au,Cu)-
bn-
10µm
90 10 434 40#13
4
bn-
-bn
-(Au,Cu)
30µm
90 10 434 40-2 #12
5 (Au,Cu)|
-cp
10µm
90 10 434 40-2 #27
(Au,Cu)\
6
bn
cp/
10µm
90 10 434 40-2 #11
7
(Au,Cu)/
bn
90 10 434 40-2 #26 10µm
8
bn
-(Au,Cu)
10µm
90 10 434 40-2 #8
9
-cp
-(Au,Cu)
10µm
90 10 434 40-2 #3
(Au,Cu)| 10
bn-
10µm
90 10 434 40-2 #6
11
/bn
bn-
(Au,Cu)/
10µm
90 10 434 70-2 #3

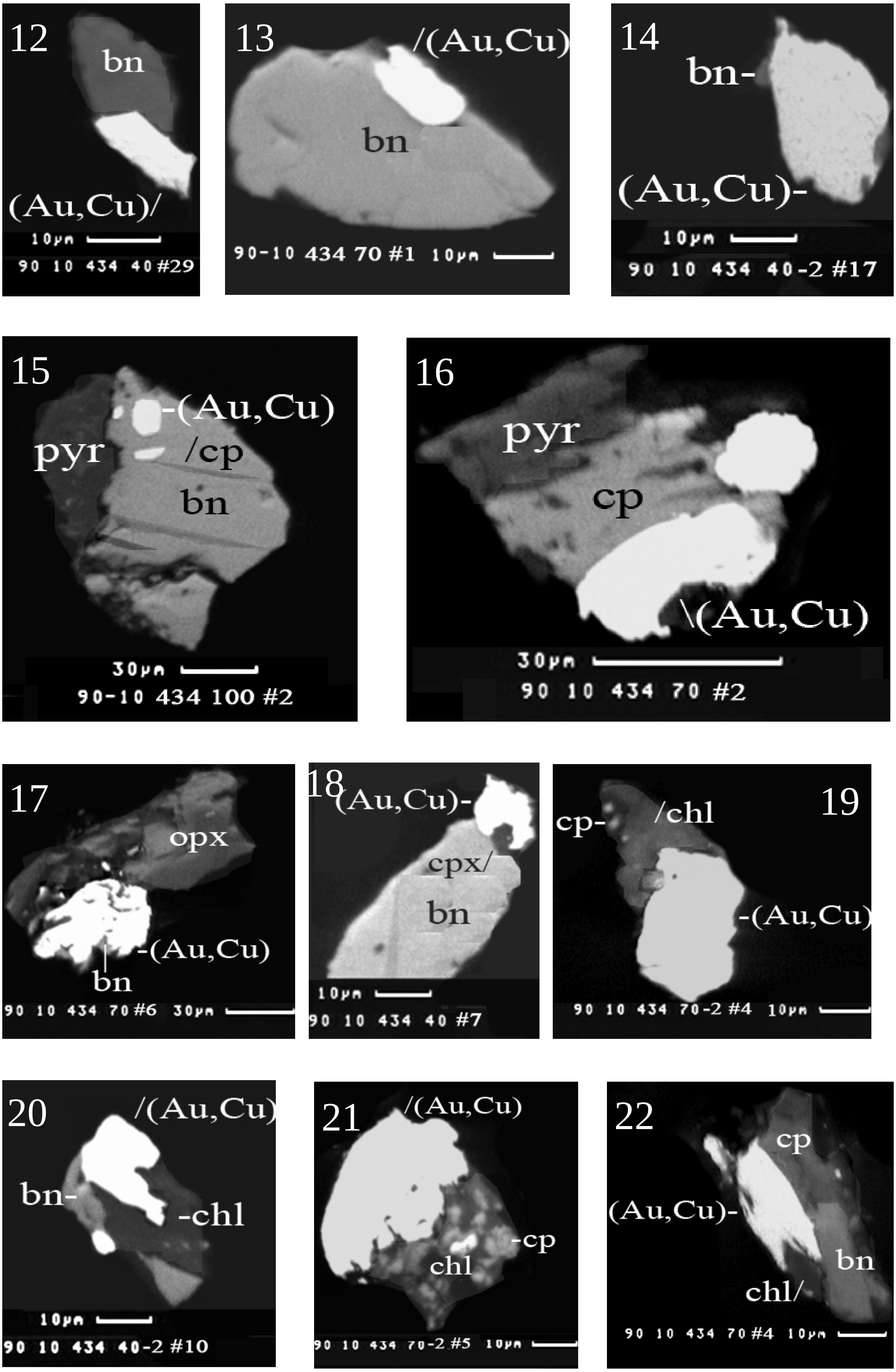
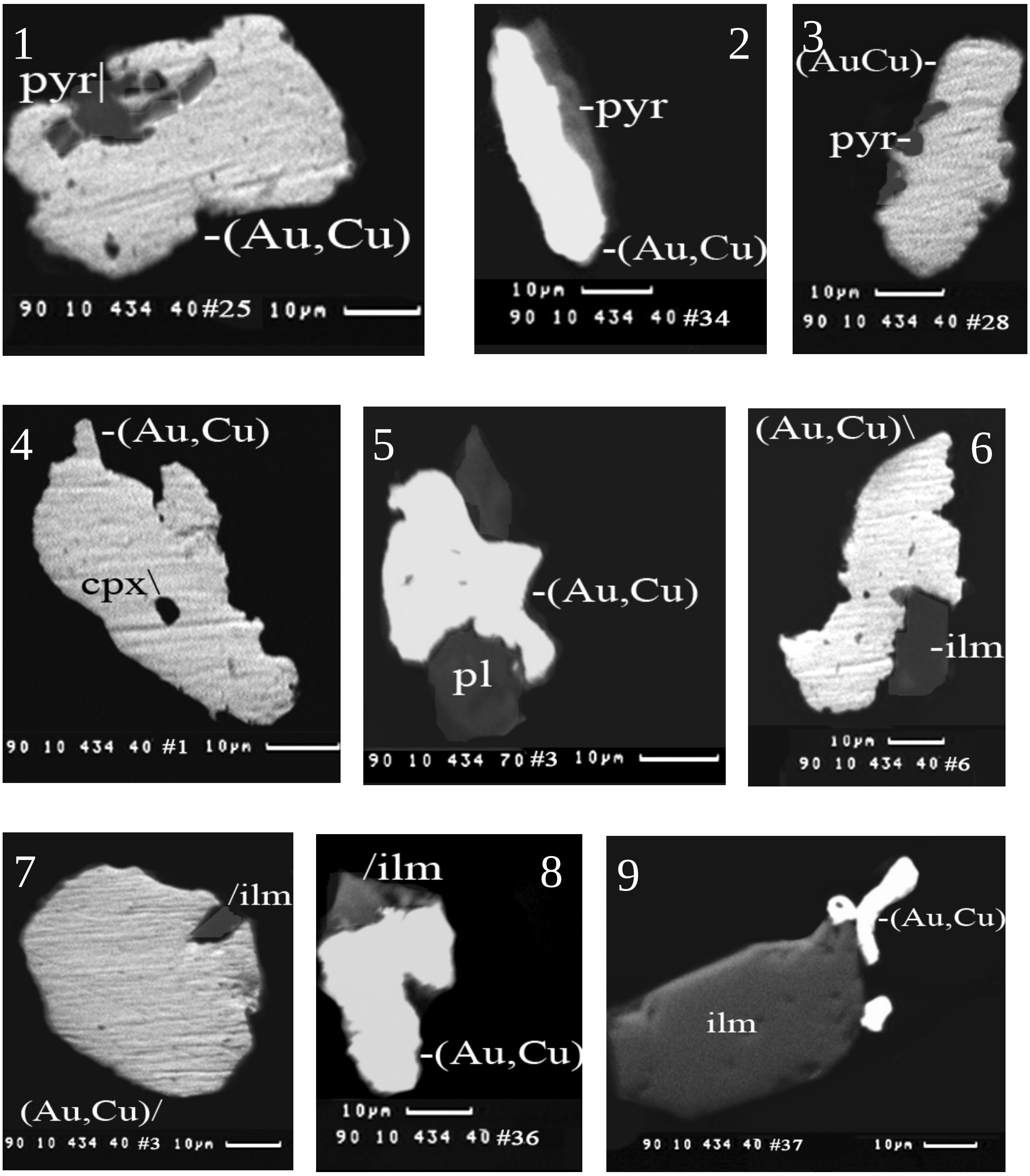

12
bn
(Au,Cu)/
10μm
90 10 434 40 #29
13
/(Au,Cu)
bn
90-10 434 70 #1 10μm
14
bn-
(Au,Cu)-
10μm
90 10 434 40-2 #17
15
-(Au,Cu)
pyr
/cp
bn
30μm
90-10 434 100 #2
16
pyr
cp
\(Au,Cu)
30μm
90 10 434 70 #2
17
opx
-(Au,Cu)
bn
90 10 434 70 #6 30μm
18
(Au,Cu)-
cpx/
bn
10μm
90 10 434 40 #7
19
cp-
/chl
-(Au,Cu)
90 10 434 70-2 #4 10μm
20
/(Au,Cu)
bn-
-chl
10μm
90 10 434 40-2 #10
21
/(Au,Cu)
-cp
chl
90 10 434 70-2 #5 10μm
22
cp
(Au,Cu)-
bn
chl/
90 10 434 70 #4 10μm

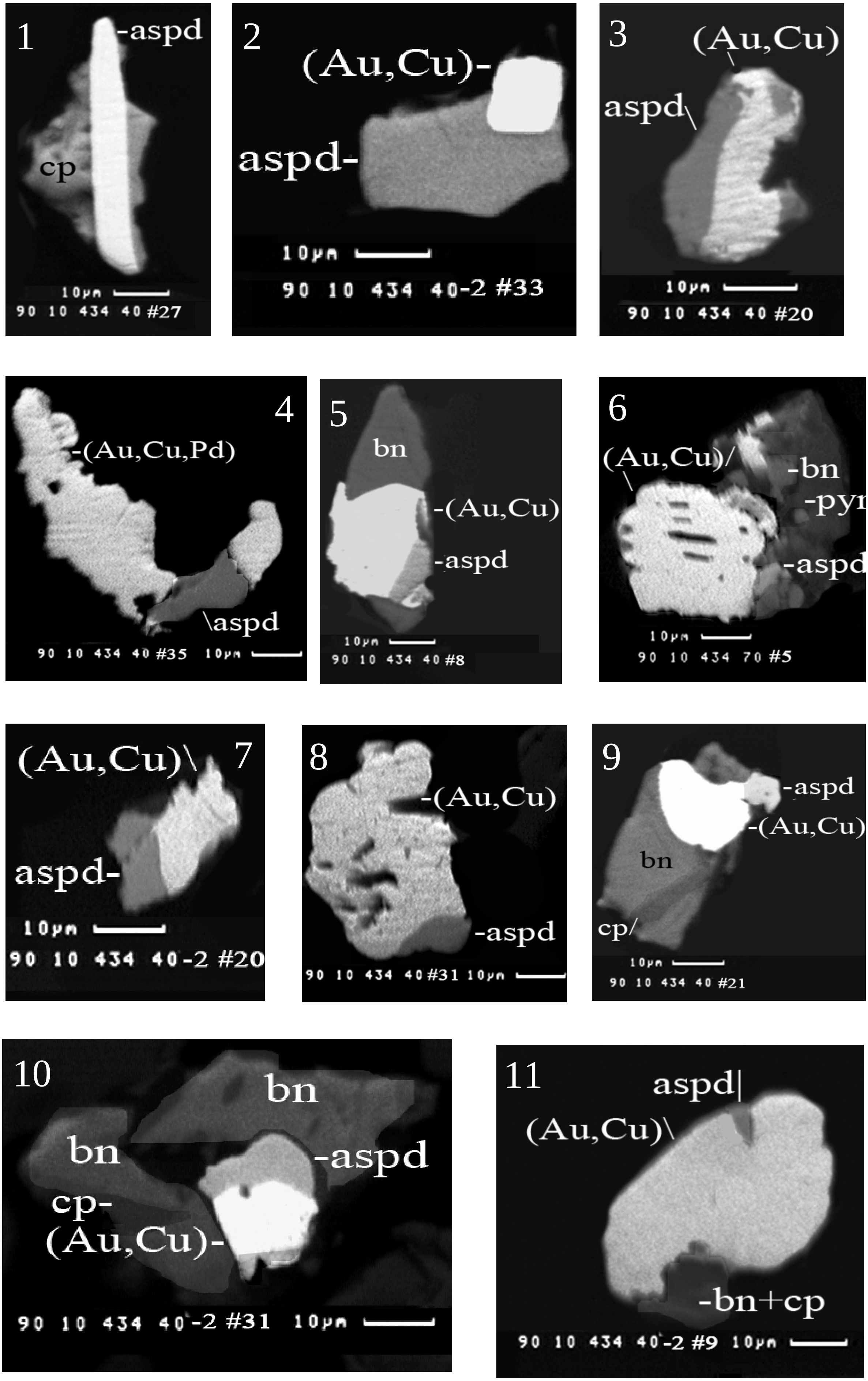
Plate 8



Grains of (Au,Cu,Ag) alloy associated with rock-forming minerals (**ag**, **ag-L** associations) in heavy mineral HS-concentrates of sample 90-10 434 (grains 1-9); SEM-images (BIE). Abbreviations: (Au,Cu): alloy; pyr: pyroxene; cpx: clinopyroxene; pl: plagioclase; ilm: ilmenite.

Plate 9

Pd-arsenides-containing grains of arsenopalladinite, guanglinite and palladoarsenide, (1-17) and atokite-bearing grain (18), heavy mineral HS-concentrates of sample 90-10 434 ; SEM-images (BIE). Abbreviations: *Sulphides*: cp: chalcopyrite; bn: bornite; pyr: pyrrhotite; *PGMs and Au-minerals*: aspd: arsenopalladinite; sp: sperrylite; gng: guanglinite; plas: palladoarsenite; at: atokite; and alloys of Au-Cu-Pd).


1
-aspd
cp
10μm
90 10 434 40 #27
2
(Au,Cu)-
aspd-
10μm
90 10 434 40-2 #33
3
(Au,Cu)
aspd\
10μm
90 10 434 40 #20
4
-(Au,Cu,Pd)
\aspd
90 10 434 40 #35 10μm
5
bn
-(Au,Cu)
-aspd
10μm
90 10 434 40 #8
6
(Au,Cu)/
-bn
-aspd
10μm
90 10 434 70 #5
(Au,Cu)\
7
aspd-
10μm
90 10 434 40-2 #20
8
-(Au,Cu)
-aspd
90 10 434 40 #31 10μm
9
-aspd
-(Au,Cu)
bn
cp/
10μm
90 10 434 40 #21
10
bn
bn
-aspd
cp-
(Au,Cu)-
90 10 434 40-2 #31 10μm
11
aspd|
(Au,Cu)\
-bn+cp
90 10 434 40-2 #9 10μm

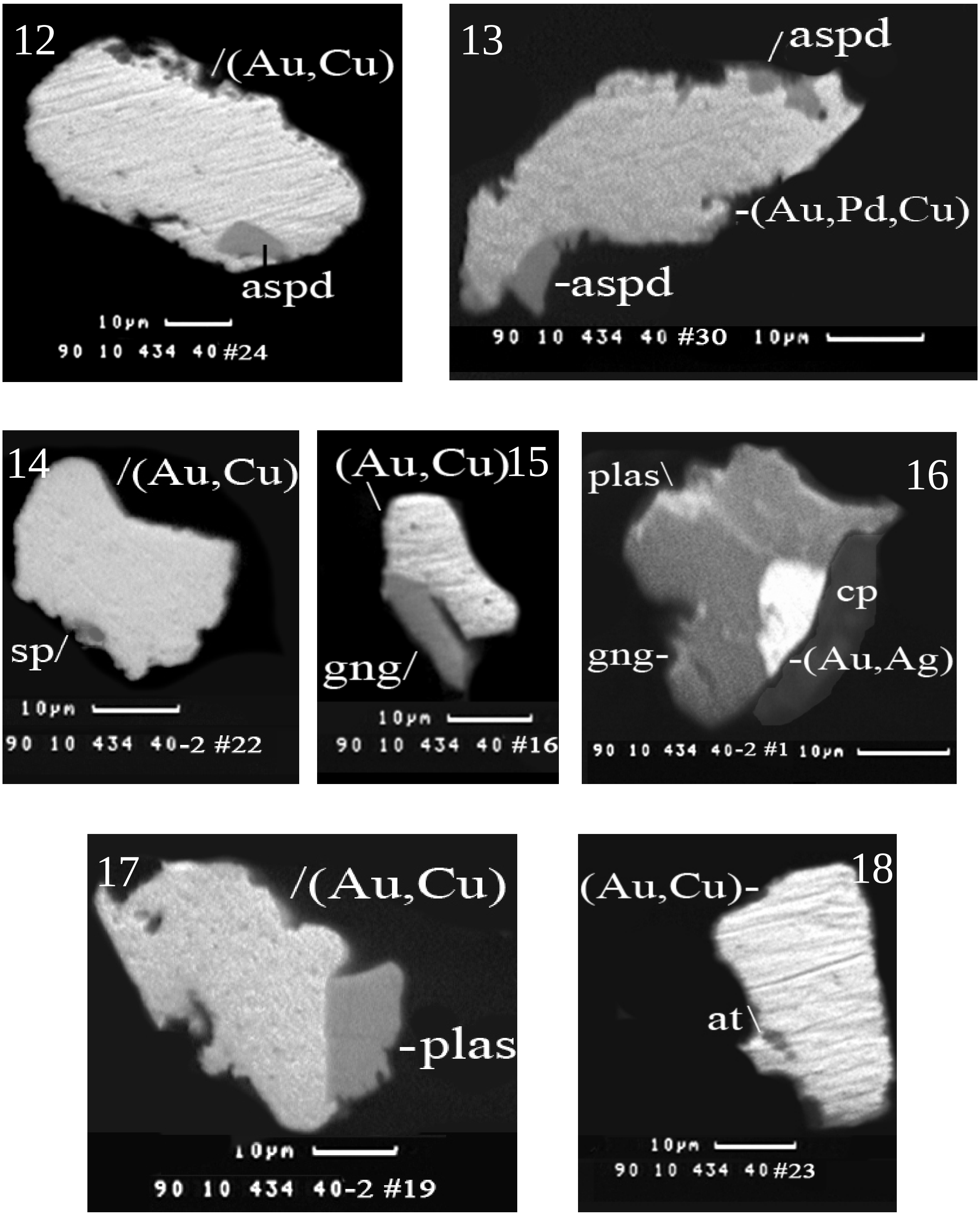
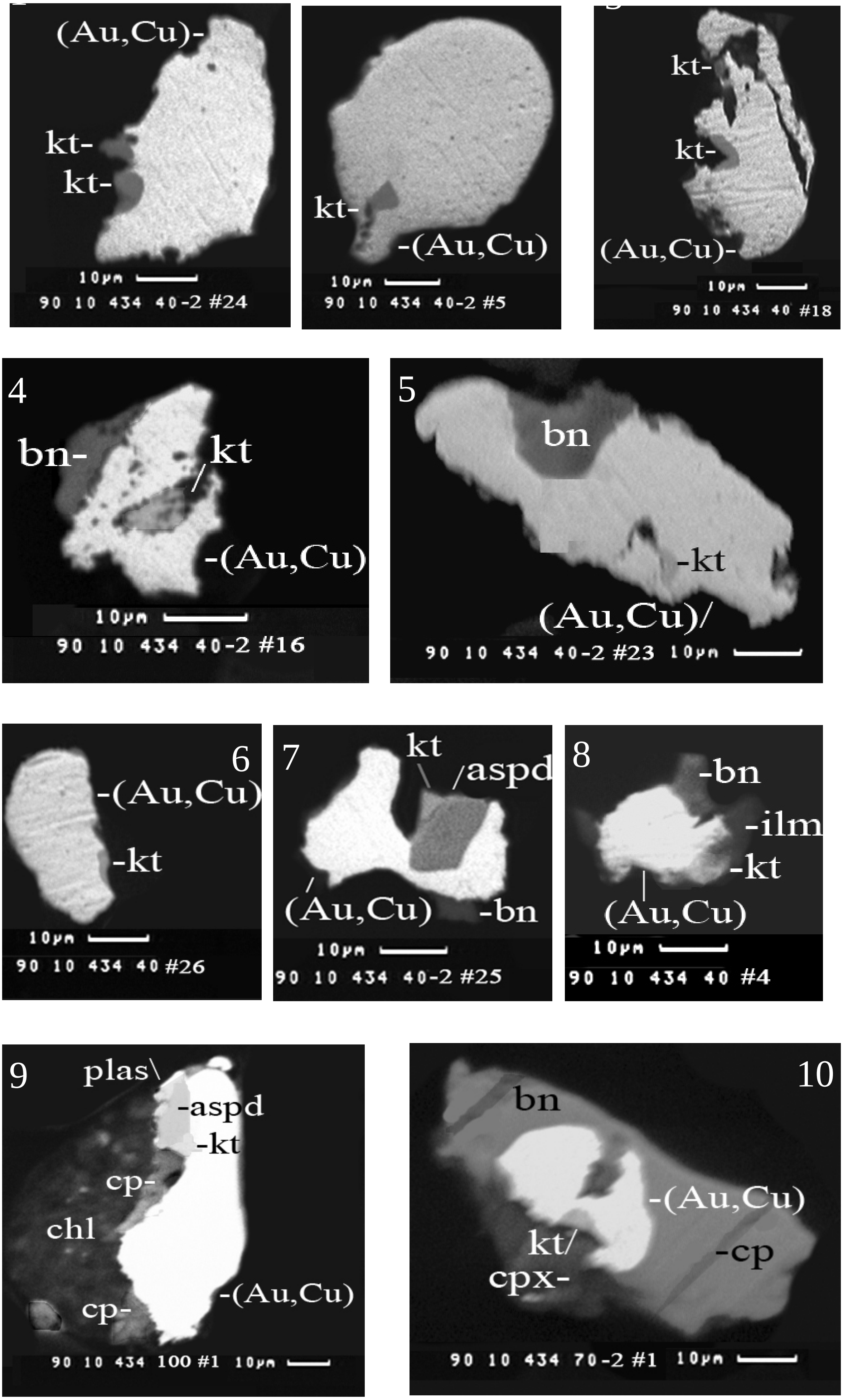
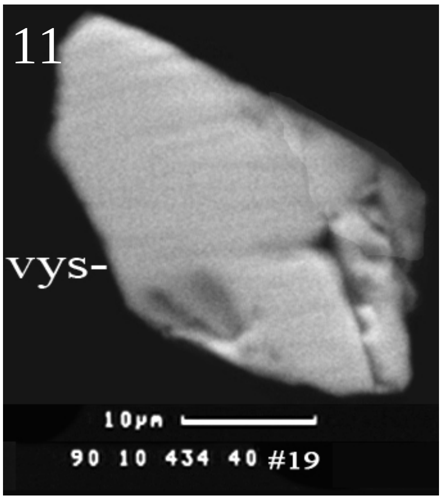
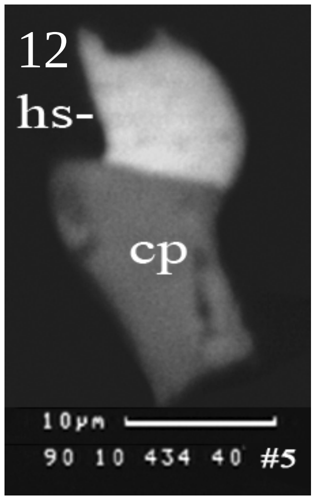

12
/(Au,Cu)
aspd
10μm
90 10 434 40 #24
13
/aspd
-(Au,Pd,Cu)
-aspd
90 10 434 40 #30 10μm
14
/(Au,Cu)
sp/
10μm
90 10 434 40-2 #22
(Au,Cu)15
\
gng/
10μm
90 10 434 40 #16
plas\
16
cp
gng-
-(Au,Ag)
90 10 434 40-2 #1 10μm
17
/(Au,Cu)
-plas
10μm
90 10 434 40-2 #19
(Au,Cu)-
18
at\
10μm
90 10 434 40#23

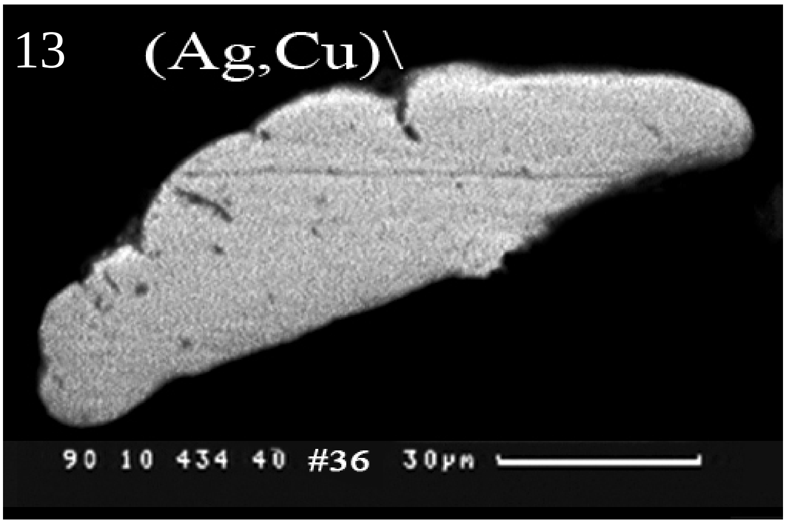
Plate 10

Kotulskite-containing grains (1-10) and grains of vysotskite (11), hessite (12) and native silver (13) in heavy mineral HS-concentrates of sample 90-10 434; SEM-images (BIE). Abbreviations: *Sulphides:* bn: bornite; cp: chalcopyrite; *precious minerals*: kt: keithconnite; aspd: arsenopalladinite; plas: palladoarsenite; vys: vysotskite; hs: hessite and alloys (Au,Cu) and (Ag,Cu); *rock forming minerals:* ilm: ilmenite; chl: chlorite; cpx: clinopyroxene.


(Au,Cu)-
kt-
kt-
10μm
90 10 434 40-2 #24
kt-
-(Au,Cu)
10μm
90 10 434 40-2 #5
kt-
kt-
(Au,Cu)-
10μm
90 10 434 40 #18
4
bn-
kt
-(Au,Cu)
10μm
90 10 434 40-2 #16
5
bn
-kt
(Au,Cu)/
90 10 434 40-2 #23 10μm
6
-(Au,Cu)
-kt
10μm
90 10 434 40 #26
7
kt
/aspd
(Au,Cu)
-bn
10μm
90 10 434 40-2 #25
8
-bn
-ilm
-kt
(Au,Cu)
10μm
90 10 434 40 #4
9
plas\
-aspd
-kt
cp-
chl
cp-
-(Au,Cu)
90 10 434 100 #1 10μm
10
bn
-(Au,Cu)
kt/
cpx-
-cp
90 10 434 70-2 #1 10μm


11
vys-
10μm
90 10 434 40 #19


12
hs-
cp
10μm
90 10 434 40 #5


13
(Ag,Cu)\
90 10 434 40 #36
30μm