On cooperite, braggite, and vysotskite

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Abstract

Detailed mineralogical analyses of cooperite, braggite, and vysotskite, together with phase equilibrium studies, reveal that, though there is no uncertainty regarding the identity of cooperite (PtS;P4_2/mmc), one may consider braggite (Pt,Pd)S and vysotskite PdS to be nickeloean members of an isomorphous solid-solution series (Pd,Pt)S (P4_2/m). The results also suggest that this solid-solution series (braggite series) may be subdivided by restricting the name vysotskite to those members with less than about 10 mole percent PtS. Cooperite and braggite can both form at magmatic temperatures of 1000°C or above, but vysotskite is only found at submagmatic temperatures, possibly by crystallization from a residual immiscible sulfide-rich melt or by solid-state reaction.

Introduction

Cooperite, braggite, and vysotskite are the only Pt-Pd sulfide minerals with ideal compositions in the system Pt-Pd-S. Cooperite is ideally PtS, braggite (Pd,Pt)S, and vysotskite PdS. All analyses, however, report the presence of significant amounts of Ni, so mineralogically they must be considered as being in the system Pt-Pd-Ni-S. We aim to clarify the nomenclature and to present new data on the compositions of the minerals. It is a pleasure to be able to do so in the Frondel-Hurlbut issue of The American Mineralogist, because these two distinguished mineralogists have clarified so many similarly confusing issues in the nomenclature of minerals.

Braggite and cooperite are both important platinum-group minerals (PG-minerals) and are known from many areas of the world; in the great Merensky Reef deposits of the Bushveld Igneous Complex in the Transvaal they are major ore minerals. Vysotskite has not so far been found in sufficient quantities to be considered an important ore mineral. First discovered in the Noril'sk deposits of the USSR and reported by Genkin and Zvyagintsev (1962), vysotskite has since been reported, but not documented in detail, from the Stillwater Complex of Montana (Cabri and Laflamme, 1974) and the Lac des Isles deposit, Ontario (Cabri and Laflamme, 1976).

In this note we report new data on all three minerals from the Precambrian Stillwater Complex of Montana. Page et al. (1976) discussed the variations of PG-elements in the different mafic and ultramafic layers of the complex. In the layers identified by Page et al. as the Banded and Upper Zones we have identified, for the first time, the three minerals in the same deposit. The three minerals have not been found in contact so it is probable that the assemblage does not represent equilibrium, and its true significance can only be guessed at.

Previous mineralogical studies

Cooperite

Cooperite was discovered in samples from the Bushveld by Cooper (1928) and named by Wagner (1929) following a suggestion by a Mr. Wartenweiller in a published discussion following presentation of Cooper's paper. Bannister and Hey (1932) determined the mineral to be tetragonal with a = 4.91 and
c = 6.10 Å. Though they recognized that this was a c face-centered cell and that the true primitive cell was
a = 3.47, c = 6.10 Å, space group P4\textsubscript{2}/mnm, they
nevertheless used the centered cell in order to empha-
size the relationship to the unit cell of platinum.
Berry and Thompson (1962) reported a unit cell with
a = 3.48 and c = 6.11 Å, Z = 2, in close agreement
with the primitive cell of Bannister and Hey. In their
powder pattern, however, they observed but could
not index three lines at 2.81 (2), 1.765 (6), and
1.397 Å (v) respectively. Genkin (1968), reporting on
coperite from two different locations in the Noril'sk
area, presented two new powder patterns. Neither
pattern included the two weak lines (2.81 and
1.397 Å) of Berry and Thompson, suggesting they
were probably due to impurity admixtures in the
Berry and Thompson sample. Both of the Noril'sk
sample patterns contained the strongest line reported
by Berry and Thompson, observed at 1.763 and
1.770 Å respectively, thus strongly suggesting that it
belonged to the pattern. The solution to the problem
becomes apparent from the work of Grønvold et al.
(1960), who studied synthetic PtS, for which they
obtained a cell with a = 3.47 Å and c = 6.106 Å. The
Grønvold powder pattern contains a strong reflection
at 1.754 Å, which is indexed as (103).

Cooperite makes up a significant fraction of the
PG-minerals present in areas of the Bushveld Com-
plex where the Merensky Reef is mined e.g. 13.36
volume percent average from four areas in the West-
ern Transvaal, Vermaak and Hendriks (1976); 10.3
volume percent at the Western Platinum mine, Bry-
nard et al. (1976); and 25 volume percent at the Atok
Platinum mine, Schwellnus et al. (1976). In spite of
the significance of cooperite in the Merensky Reef,
the only published microprobe analyses are those of
Schwellnus et al. (1976) and Brynard et al. (1976),
together with a single analysis by A. M. Clark re-
ported by Cabri (1972). The five cooperite analyses of
Schwellnus et al. (1976) are from samples from the east-
ern Bushveld, and they reveal a range of compo-
sition for Pd (by weight) from 0.15 to 5.78 percent and
for Ni from 0.68 to 1.18 percent; the analyses also
reveal Pb (1.14 to 1.35 percent) and Bi (0.41 to 0.71
percent). Six analyses of cooperite from the western
Bushveld by Brynard et al. (1976) have a narrower
range for Pd from 0.5 to 1.5 percent, with Ni ranging
from 0.6 to 1.6 percent and traces of Rh.

Braggite

Braggite was named by Bannister and Hey (1932)
for a tetragonal mineral with a = 6.37, c = 6.58 Å,
space group P4\textsubscript{2}/m, Z = 8, and a composition ap-
proximating "... (Pt,Pd,Ni)S containing about 20
percent Pd and 5 percent Ni..." Braggite is even
more abundant than cooperite in some mines of the
Bushveld Complex. It averages 35.9 volume percent
of the PG-minerals from four areas in the Western
Transvaal (Vermaak and Hendriks, 1976) and 60 vol-
ume percent at the Atok Platinum mine in the eastern
Bushveld (Schwellnus et al., 1976).

The crystal structure of braggite was determined by
Childs and Hall (1973) on a sample from the Potgi-
tersrust district, Transvaal. They reported cell param-
eters of a = 6.380 (1), c = 6.570 (1) Å, Z = 8. Childs
and Hall also proposed that 2 Pd atoms were "... the
minimum requirement in the formation of the PdS
(braggite or vysotskite) structure rather than the PtS
(cooperite) structure." However, four of the six brag-
gite analyses reported by Schwellnus et al. (1976)
have less than two atoms of Pd per cell, thus casting
considerable doubt on the Childs and Hall sugges-
tion.

Vysotskite

In 1962, Genkin and Zvyagintsev reported the min-
eral vysotskite, for which they indicated the formula
(Pd,Ni)S, though they did not consider Ni to be an
essential constituent. They found the mineral to be
tetragonal with a = 6.371 and c = 6.540 Å, and the
powder pattern was very similar to that reported for
braggite. The powder pattern was also very similar to
that of synthetic PdS, for which Gaskell (1937) had
reported a = 6.43 (2) and c = 6.63 (2) Å, space group
P4\textsubscript{2}/m, Z = 8. These data suggested strongly that
braggite and vysotskite were members of an iso-
morphous series of which PdS was the end-member
composition.

Phases in the system Pt–Pd–S

The ternary phase relations for Pt–Pd–S at 1000°C
were reported by Skinner et al. (1976). Those at
800°C have now been completed and are reported in
Figure 1. No solid phases more sulfur-rich than PtS
or PdS appear, thus we can confine discussion to the
phase-volume PtS–PdS–Pd–Pt. Four phases appear:
a continuous alloy from Pt to Pd, a liquid field lo-
cated on the Pd–PdS join, and two sulfides. The first
sulfide is a solid solution identical with cooperite
extending from PtS, along the composition join to-
ward PdS, to (Pt\textsubscript{0.70}Pd\textsubscript{0.30})S at 1000°C and
(Pt\textsubscript{0.54}Pd\textsubscript{0.46})S at 800°C. The second is a phase identi-
cal in properties to braggite. At 1000°C the braggite-
like phase ranges in composition from (Pd\textsubscript{0.40}Pd\textsubscript{0.60})S
to \((Pd_{0.84}Pt_{0.16})S\), but does not reach the composition \(PdS\). \(PdS\) is stable below 912 ± 5°C, and at 800°C the braggite-like solid solution ranges from \(PdS\) to \((Pd_{0.76}Pt_{0.24})S\).

Two conclusions can immediately be drawn from the synthesis studies. First, braggite and cooperite are not polymorphs, even though the Pd-rich limit of cooperite might slightly overlap the Pt-rich limit of braggite. Second, pure \(PdS\), with powder patterns identical to vysotskite, is compositionally continuous with a phase identical in all X-ray properties with braggite. Clearly, therefore, the identity of braggite and vysotskite as minerals must rest on their composition ranges.

Analyses of PG-sulfide minerals

We had available to us samples of PG-minerals from the Stillwater Complex, the Rustenburg area of the Merensky Reef, Potgietersrust, and Lac des Isles. The Stillwater samples were collected in 1975 from the West Fork adit of the property worked by Johns-Manville Corporation (1, 2, 4) and supplemented by samples 5, 6 and 7 provided by the Corporation. Using local mine terminology, sample 1 came from the Bastard zone, which is a thin (2-6 in.) pyroxene cumulate layer situated some 6 feet stratigraphically below the main olivine cumulate horizon (main marker) which contains large pyroxene oikocrysts; sample 2 came from the “dark anorthosite” which forms part of the ore horizon immediately above the main marker; and sample 4 came from an adjoining section of the same ore horizon, referred to as the “tri-colored anorthosite.” The three samples provided by the Corporation are located as follows: sample 5(1824-PP-20) is a sulfide concentrate milled and floated from a bulk sample taken from the West Fork adit. Sample 6(DDH 77-73-13) is from the Camp zone, located within the lower part of the Banded zone and 4.7 miles WNW along strike from the West Fork adit. Sample 7(789-T-1-1) is from a pyroxene cumulate layer in a trench in the southeast corner of claim Coors 8, located 6.5 miles WNW along strike from the adit.

The Lac des Isles vysotskite sample was discovered in a partly crushed drill core sample, PI4-7, and the Rustenburg (MI9398) and Potgietersrust (MI9388) samples were PG-mineral concentrates from the Royal Ontario Museum collections.

The samples that needed crushing and concentration were processed as outlined by Cabri and Laglafame (1974). X-ray powder diffraction data were obtained by the film method using Gandolfi and Debye-Scherrer cameras. Film-shrinkage corrections were applied and the unit-cell parameters were refined by a least-squares computer program PARAM (Stewart et al., 1972).

The compositions were determined using a Materials Analysis Company Model 400 electron probe microanalyzer, operated at 25 and 20 kV with a specimen current of about 0.03 microamperes. The following lines and synthetic standards were used: 
\[PtLa(Pt_{0.7}Pd_{0.3}S, Pt_{1}Fe, Pt_{1}Fe, Pt_{5}Fe_{2})\]; 
\[PdLa(Pt_{0.7}Pd_{0.3}S, PdS, metal); SKa(Pt_{0.7}Pd_{0.3}S, PdS)\]; 
\[CuK\alpha(Pt_{0.6}Fe_{0.4}Cu_{0.16}); FeK\alpha(Pt_{3}Fe, Pt_{5}Fe_{2})\].

Corrections to these X-ray data were applied with a modified version of the EMPA VII computer program of Rucklidge and Gasparrini (1969).

Results

Fifty grains of Pt-Pd sulfides from the Stillwater samples were analyzed and the results are plotted in Figure 2. In addition, analyses of grains from the Rustenburg, Potgietersrust, and Lac des Isles samples are also plotted in Figure 2, together with analyses reported by Laputina and Genkin (1975), Brynard et al. (1976) and Schwellnus et al. (1976). Some analyses
are given in Table 1 while Table 2 lists all the analyses. A considerable number of grains were not homogeneous, especially grains of vysotskite and braggite. These are identified as filled circles with a HOM index >3 in Figure 2, and the range of variability between Pt and Pd, in particular, is demonstrated by the bars in Figure 3. A few grains were X-rayed to confirm identifications and to provide X-ray data.

It is apparent that cooperite approaches an ideal Ni-free composition more closely than do braggite and vysotskite, and no difficulty or uncertainty clouds its identity. From analyses to date, it appears that braggite and vysotskite contain a minimum of about 10 mole percent Ni replacing the other metals. The spread shown by these analyses, when plotted in the PdS-PtS-NiS composition triangle (Fig. 3), highlights the problem concerning the nomenclature of vysotskite-braggite.

Both braggite and vysotskite were named without specification of compositional ranges, prior to knowledge of phase relations in the Pt-Pd-S system, and prior to the extensive microprobe analyses now available from a wide range of samples. It has generally come to be accepted that braggite is (Pt,Pd,Ni)S (P4/m symmetry), with a composition between the compositional end-members PdS and PtS. It is interesting to note, however, that the average composition from in situ analyses for 19 homogeneous grains is very close to that given by Bannister and Hey (1932). The data plotted in Figure 2, despite the uncertainties shown in Figure 3, do suggest compositional groupings which might be used to clarify the nomenclature of braggite and vysotskite.

Vysotskites are, as defined by Genkin and Zvyagintsev, (Pd,Ni)S compounds. All analyzed samples contain a small amount of Pt as well, but in naturally occurring samples a distinct break separates vysotskites from braggites (Fig. 2). Thus, vysotskites can be defined as all members of the braggite solid solution series containing less than 10 mole percent PtS.

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Table 1. Electron probe analyses of cooperite, braggite, and vysotskite

<table>
<thead>
<tr>
<th></th>
<th>Pt</th>
<th>Weight percent</th>
<th>Atomic proportions</th>
<th>Total</th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Cooperite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Pt</td>
<td>85.8</td>
<td>0.77</td>
<td>0.50</td>
<td>14.1</td>
<td>101.17</td>
<td>0.98</td>
<td>0.02</td>
<td>0.02</td>
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<tr>
<td>Low Pt</td>
<td>71.8</td>
<td>4.0</td>
<td>7.3</td>
<td>17.3</td>
<td>100.4</td>
<td>0.69</td>
<td>0.07</td>
<td>0.23</td>
</tr>
<tr>
<td>AVE(14 anal.)</td>
<td>83.5</td>
<td>1.4</td>
<td>1.2</td>
<td>14.5</td>
<td>100.6</td>
<td>0.94</td>
<td>0.03</td>
<td>0.04</td>
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<tr>
<td>Grain C*</td>
<td>83.5</td>
<td>1.4</td>
<td>0.64</td>
<td>14.2</td>
<td>99.74</td>
<td>0.96</td>
<td>0.03</td>
<td>0.02</td>
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<td>Braggite</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Pt</td>
<td>68.1</td>
<td>8.5</td>
<td>5.6</td>
<td>16.7</td>
<td>98.9</td>
<td>0.67</td>
<td>0.15</td>
<td>0.18</td>
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<tr>
<td>Low Pt</td>
<td>40.9</td>
<td>33.9</td>
<td>5.1</td>
<td>19.6</td>
<td>99.5</td>
<td>0.34</td>
<td>0.52</td>
<td>0.14</td>
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<tr>
<td>AVE(19 anal.)</td>
<td>56.4</td>
<td>20.3</td>
<td>5.1</td>
<td>18.2</td>
<td>100.0</td>
<td>0.51</td>
<td>0.34</td>
<td>0.15</td>
</tr>
<tr>
<td>Grain H*</td>
<td>64.6</td>
<td>13.5</td>
<td>3.9</td>
<td>17.1</td>
<td>99.1</td>
<td>0.63</td>
<td>0.24</td>
<td>0.12</td>
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<tr>
<td>Vysotskite</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>High Pd (Gr. 6)*</td>
<td>2.0</td>
<td>69.5</td>
<td>3.9</td>
<td>23.7</td>
<td>99.1</td>
<td>0.01</td>
<td>0.89</td>
<td>0.09</td>
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<tr>
<td>Low Pd</td>
<td>4.3</td>
<td>65.7</td>
<td>5.3</td>
<td>23.7</td>
<td>99.0</td>
<td>0.03</td>
<td>0.84</td>
<td>0.12</td>
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<tr>
<td>AVE(3 anal.)</td>
<td>2.2</td>
<td>67.6</td>
<td>5.9</td>
<td>24.1</td>
<td>99.8</td>
<td>0.02</td>
<td>0.85</td>
<td>0.13</td>
</tr>
</tbody>
</table>

*Grain X-rayed; Bi, Pb sought for but not detected. Analyses used in averaging had HOM<3.
Braggite would then refer to all compounds in the series with a PtS content in excess of 10 mole percent. The reason for two compositional groups in a continuous solid solution series is an interesting point, and a possible answer is suggested by the phase relations in Figure 1. Braggites formed at magmatic temperatures of 1000° C or above must all contain 16 mole percent PtS or more, because phases containing lower Pt contents are not stable (Skinner et al., 1976). However, as temperatures decline, a sulfide melt can remain stable down to almost 600°C, and, as pointed out by Skinner et al. (1976), this melt probably plays an important role in the crystallization sequence of PG-minerals. One of the phases that will crystallize from the cooling sulfide melt is a braggite-series mineral. As the temperature drops, the braggite mineral will be increasingly Pd-rich and will, in fact, fall in the vysotskite composition range. Thus, we suggest that most braggites are probably formed at high, magmatic temperatures, while all vysotskites are formed at sub-magmatic temperatures. Unless an early-formed braggite grain happens, by chance, to be adjacent to a late-formed vysotskite grain and thereby able to become homogenized, we should expect to observe separate compositional populations of braggite and vysotskite, even if the two should be found to coexist in the same rock.

Crystal chemistry

The cooperite X-ray powder diffraction pattern (Table 3) is free of the extraneous lines observed by some previous workers and is also the first X-ray pattern reported from an analyzed grain of cooperite. The braggite X-ray powder diffraction pattern (Table 4) has better resolution than the pattern listed in PDF 9-421 [e.g. the (102) and (210) reflections are resolved]. The vysotskite X-ray powder diffraction pattern is compared to that of Genkin and Zvyagintsev (1962) which has four bracketed unindexed reflections (Table 5), presumed to be beta. The considerably higher intensity for the (200) reflection for the Noril'sk's sample is probably due to its enhancement by the beta for the (210). Unit cells and other physical data are listed in Table 6, the space group assignments for cooperite and vysotskite having been confirmed by single crystal examination with a precession camera in this study. The cooperite cell dimensions are very close to those reported by Grønvold et al. (1960) for synthetic PtS. Braggite cell dimensions compare favourably with those reported by Childs and Hall (1973) for a grain with a similar composition. Except for some differences in intensities, the powder pattern for vysotskite is the same as that reported for Genkin and Zvyagintsev's (1962) in PDF 15-151, though the calculated c-dimension in Table 6 is a little longer than that given by Genkin and Zvyagintsev. These data show that, while it is possible to distinguish cooperite from braggite, it is impossible to differentiate between braggite and vysotskite by X-ray methods, because substitution of Pt for Pd leads only to very small shifts in cell edges in the braggite-vysotskite cell structure.

Childs and Hall (1973) inferred the structure of braggite from Gaskell's (1937) determination of the structure of PdS. They tested five different configura-

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Table 3. X-ray powder diffraction data of cooperite

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<tr>
<th>hkl</th>
<th>dmeas</th>
<th>dcalc</th>
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<tbody>
<tr>
<td>101</td>
<td>3.45</td>
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<td>010</td>
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<td>110</td>
<td>2.290</td>
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<td>1.911</td>
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<tr>
<td>113</td>
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114.6 mm Debye Scherrer camera, Ni-filtered CuKα radiation, λ = 1.5405. ROM M19388, gr. C in Table 1, from Potgietersrust.
point out that this would also require additional disordered replacement of the Pt positions by Pd. This can only be confirmed by further crystal structure investigation of different ordering models.

**Mineral associations**

Though the three minerals occur in the Stillwater samples, they were not observed to coexist. Cooperite Pt_{0.98}Pd_{0.02}Ni_{0.05}S_{0.99} and braggite Pd_{0.50}Pt_{0.50}Ni_{0.05}S_{0.92} were found coexisting in only one sample (No. 4). Cooperite and also braggite occurred as contiguous grains in the Rustenburg samples, but microanalyses revealed very little compositional variation in the coexisting mineral pairs, though the compositions of

<table>
<thead>
<tr>
<th>Table 4. X-ray powder diffraction data of braggite</th>
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<td><img src="image" alt="X-ray powder diffraction data of braggite" /></td>
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<table>
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<th>Table 5. X-ray powder diffraction data of vysotskite</th>
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<td><img src="image" alt="X-ray powder diffraction data of vysotskite" /></td>
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Table 6. Physical data for the Pt-Pd sulfide minerals

<table>
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<tr>
<th>Mineral</th>
<th>Composition</th>
<th>Space Group</th>
<th>Cell Dimensions Å</th>
<th>Cell vol. Å³</th>
<th>Dx g cm⁻³</th>
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</thead>
<tbody>
<tr>
<td>cooperite¹</td>
<td>Pt₀.₉₆Pd₀.₀₃Ni₀.₀₂S₀.₉₉</td>
<td>P₄₁/mma</td>
<td>3.465(3)</td>
<td>6.104(3)</td>
<td>73.286</td>
</tr>
<tr>
<td>braggite²</td>
<td>Pt₀.₆₃Pd₀.₂₄Ni₀.₁₂S₁.₀₁</td>
<td>P₄₁/m</td>
<td>6.367(3)</td>
<td>6.561(6)</td>
<td>265.974  33.246 9.383</td>
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<tr>
<td>vysotskite³</td>
<td>Pd₀.₈₉Pt₀.₀₁Ni₀.₀₉S₁.₁₀</td>
<td>P₄₁/z</td>
<td>6.368(3)</td>
<td>6.562(3)</td>
<td>266.098  33.262 6.705</td>
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</tbody>
</table>


the braggites were significantly different to the Stillwater sample. Cooperite ranged from Pt₀.₉₈Pd₀.₀₂Ni₀.₀₂S₀.₉₉ to Pt₀.₉₈Pd₀.₀₁Ni₀.₀₂S₀.₉₉ and braggite from Pt₀.₉₆Pdₐ₉₄Ni₁₆S₁.₀₁ to Pt₀.₉₆Pd₀.₂₈Ni₁₄S₁.₀₁. The significance of this cannot be assessed without further detailed sampling and mineralogical studies.

The occurrence of Pt-Fe alloy with cooperite or braggite was not uncommon in the Stillwater samples. These assemblages were further examined because Skinner et al. (1976) found that cooperite + isoferroplatinum + pyrrhotite was a stable assemblage in the Pt-Fe-S ternary at 1000°C. The Pt-Fe alloy grains coexisting with cooperite and braggite (Figs. 4, 5) were analyzed and, in all cases, were found to have compositions within the isoferroplatinum field reported by Cabri and Feather (1975), in good agreement with the synthetic work of Skinner et al. (1976). Typical compositions ranged from Pt₂.₉₂(Fe₀.₆₅Ni₀.₀₂Cu₀.₀₁) to Pt₃.₇₆Pd₀.₀₅(Fe₀.₀₉Ni₀.₀₆Cu₀.₀₂). The fifteen grains analyzed were too small (from less than 5 × 5 µm to about 30 × 80 µm) to extract for X-ray diffraction in order to determine whether the Pt-Fe alloy was primitive cubic isoferroplatinum or face-centered cubic ferroan platinum.

Conclusions

The composition ranges and mineral assemblages of the PG-sulfide minerals agree reasonably well with data obtained from equilibrium phase studies. The data suggest that in layered intrusive rocks, both cooperite and braggite can be formed at magmatic temperatures of 1000°C or above, while vysotskite is only formed at sub-magmatic temperatures and probably arises by crystallization from a residual immiscible sulfide-rich melt that separated from the parent magma.

We conclude that Ni is not an essential element in the formation of cooperite, braggite, or vysotskite, because each of the phases can be prepared, Ni-free, in the laboratory. Presumably the high Ni-contents reflect the origin of the three minerals as phases formed in mafic or ultramafic igneous rocks rich in Ni. Should any of the minerals be formed in other kinds of geological environments, where Ni was not readily available or was already tied up in other minerals and removed from reaction, we suggest that Ni-free or at least Ni-poor braggite, vysotskite, and cooperite could be expected.

Finally, we conclude that braggite and vysotskite are simply compositional variants of the same phase.

Fig. 4. Pt-Fe alloy inclusion (white) in braggite (light grey)-silicate intergrowth. The 10 µm long inclusion in Pt-Fe is pentlandite. Sample 1824-PP-20, Stillwater Complex.

Fig. 5. Pt-Fe alloy included in braggite coexisting with pyrrhotite (upper right, P). Sample 2, Stillwater Complex.
of which the end-member composition, PdS, has not been found in nature. We suggest that the family of minerals be called the braggite series and that all compositions containing less than 10 mole percent PtS be called vysotskite.

Acknowledgments

We would like to thank Mr. H. Keith Conn and Dr. E. L. Mann for their hospitality to one of us (L.J.C.) during a visit to the Johns-Manville Corporation operations and for samples provided. The Lac des Isles sample was obtained through Mr. J. P. Sheridan, Toronto, and the Royal Ontario Museum samples were obtained with the help of Drs. R. I. Gait and J. A. Mandarino. We are also grateful to Drs. J. T. Szymanski and T. T. Chen for useful discussions. A portion of this work was supported by NSF grant GA-27523.

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Manuscript received, March 20, 1978; accepted for publication, April 11, 1978.