# SHORT COMMUNICATIONS

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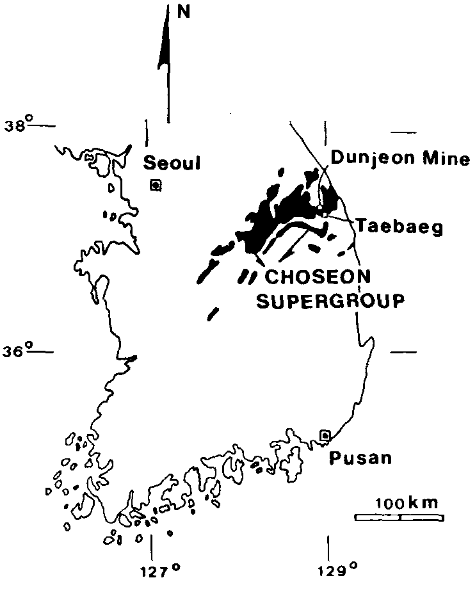
# Sb-cosalite from Dunjeon Gold Mine, Taebaeg City, Korea

COSALITE is the most common of all lead sulbismuthinide minerals, and its chemical compositions from various occurrences were found to be very close to its formula composition, $Pb_2Bi_2S_5$, and free of antimony (Koch, 1930; Klominsky *et al.*, 1971; Nedachi *et al.*, 1973; Vinogradova *et al.*, 1983; Srikrishnan and Nowacki, 1974; and Trdlicka *et al.*, 1973). However, cosalite of this composition has not been synthesized in the system $PbS–Bi_2S_3$ (Craig, 1967; Salanci and Moh, 1969; and Hoda and Chang, 1975). In a study of phase relations in the system $PbS–Bi_2S_3–Sb_2S_3$, a series of starting compositions of $Pb_2(Bi_{1-x}Sb_x)_2S_5$ with $x = 0.00$, 0.05, 0.10, 0.15, 0.20 and 0.25 was prepared at 400 °C and 500 °C by the method of Chang *et al.* (1980). Compositions of $x = 0.00$ and 0.05 produced an assemblage of lillianite + galenobismutite, while those of $x = 0.10$ and $x = 0.15$ gave lillianite + galenobismutite + Sb-cosalite. When $x = 0.25$, resultant phases are lillianite + Sb-cosalite + kobellite. A single phase was obtained with $x = 0.20$ which was characterized by X-ray powder diffraction to be an Sb-cosalite. Cell dimensions measured are $a = 19.05$ Å, $b = 24.07$ Å, and $c = 4.04$ Å. Such an Sb-cosalite was found for the first time in nature, in the Dunjeon gold deposits, and results of a mineralogical investigation are reported here in this note.

The Dunjeon gold mine is located about 20 km



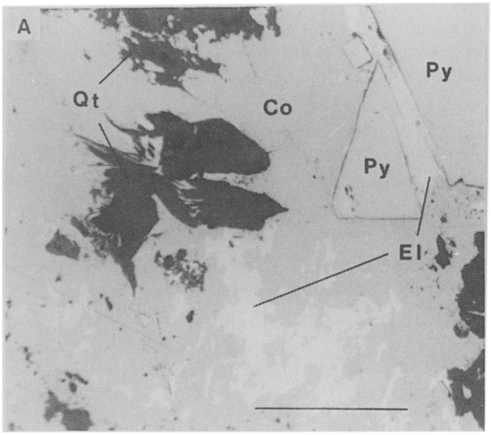


FIG. 1 (left). Map showing the location of the Dunjeon gold mine. FIG. 2 (right). Photomicrograph showing mineral association of Sb-cosalite, pyrite, electrum, and quartz. Scale bar = 150 μm.

Table 1. X-ray Powder Diffraction Data for Sb-Cosalite

| Sb-Cosalite* | | Cosalite** | | Sb-Cosalite*** | | |
|---|---|---|---|---|---|---|
| d (Å) | $I/I_0$ | d (Å) | $I/I_0$ | d (Å) | $I/I_0$ | (hkl) |
| | | 4.46 | 40 | 4.43 | 40 | 420 |
| | | 4.11 | 10 | 4.10 | 10 | 430 |
| 3.90 | s | 3.95 | 50 | 4.01 | 50 | 060 |
| | | | | 3.92 | 10 | 160 |
| | | 3.72 | 20 | 3.73 | 20 | 440 |
| | | 3.62 | 10 | 3.56 | 10 | 221 |
| 3.42 | vs | 3.44 | 100 | 3.44 | 100 | 530 |
| 3.32 | s | 3.36 | 50 | 3.39 | 50 | 360, 450 |
| | | 3.22 | 20 | 3.30 | 20 | 141 |
| 2.99 | m | 3.07 | 20 | 3.07 | 20 | 620 |
| 2.86 | s | 2.82 | 50 | 2.82 | 50 | 161 |
| | | 2.25 | 30 | 2.26 | 30 | 701 |
| 2.15 | s | 2.15 | 60 | 2.13 | 60 | 850, 770 |
| 2.04 | s | 2.04 | 50 | 2.06 | 50 | 860, 801 |

*X-ray powder diffraction data obtained in this study using Standard camera (114.59 mm), Fe-filter Co-radiation, 30 kv, 10 mA, 26 hours.

**Berry and Thompson (1962)

***Synthetic Sb-cosalite by Chang et al. (1980).

northwest of Taebaeg City, Kangwein Do, Korea (Fig. 1). Tectonically, the mine is at the northern margin of the Taebaeg basin which consists of a sequence of limestone, shale, sandstone, and quartzite of the Choseon Supergroup of Cambro-Ordovisian age (Park and Lee, 1992). Mineralization in the deposit can be divided into three stages based upon vein structures and mineral associations, and Sb-cosalite is the product of stage II. The formation temperatures and sulphur fugacities of Sb-cosalite deduced from thermodynamic considerations are 240° to 320 °C and from $10^{-13.6}$ to $10^{-17.4}$ atm (Park and Lee, 1992).

Sb-cosalite occurs widely in the galena-rich ores with boulangerite, bournonite, pyrite and electrum (Fig. 2). The mineral is always anhedral with a grain size of approximately 200 μm. X-ray powder diffraction data for the Dunjeon cosalite are presented in Table 1, along with data for cosalite from British Columbia (Berry and Thompson, 1962) and the synthetic Sb-cosalite of Chang *et al.* (1980). A reasonable match among them is observed.

Chemical compositions of cosalite from Dunjeon gold mine were analysed by electron microprobe and results are listed in Table 2. The Sb content varies from 4.99 to 6.27 wt.%, and the average of sixteen analyses gives a formula of $Pb_{2.04}(Bi_{0.70}Sb_{0.23})_2(Ag_{0.07}Cu_{0.07})_2S_5$, which correlates well with the formula of synthetic Sb-cosalite of $Pb_2(Bi_{0.08}Sb_{0.20})_2S_5$, except the Ag- and Cu-contents which are considered as soluble cations in cosalite. The chemical compositions listed in Table 2 clearly demonstrate the substitution between Bi and Sb as the increasing Sb content matches the decreasing Bi content. Such a substitution is supported by the structural analysis of cosalite (Srikrishnan and Nowacki, 1974). Of the four bismuth atoms in a cosalite unit cell, one has a five-coordinated position forming a square pyramid, and the other three are in the octahedral position where bismuth atoms usually are. It is known that antimony atoms have a higher preference than bismuth atoms for the five-coordinated position.

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Table 2. Chemical composition for Sb-cosalite from Dunjeon gold mine.

| | Weight Percent | | | | | | | Atomic Percent | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Pb | Bi | Sb | Ag | Cu | S | Total | Pb | Bi | Sb | Ag | Cu | S |
| 1. | 41.75 | 42.02 | - | - | - | 16.15 | 100.00 | 22.22 | 22.22 | - | - | - | 55.56 |
| 2. | 42.60 | 30.57 | 6.19 | 1.97 | 0.88 | 16.78 | 98.19 | 21.12 | 15.08 | 5.98 | 1.90 | 1.44 | 54.48 |
| 3. | 42.57 | 31.80 | 5.63 | 1.59 | 1.19 | 16.74 | 99.52 | 21.34 | 15.78 | 4.82 | 1.53 | 1.95 | 54.49 |
| 4. | 42.84 | 30.78 | 6.27 | 1.86 | 0.86 | 16.83 | 99.44 | 21.51 | 15.32 | 5.36 | 1.79 | 1.40 | 54.62 |
| 5. | 43.57 | 30.37 | 5.96 | 1.70 | 0.87 | 16.59 | 99.06 | 22.10 | 15.27 | 5.14 | 1.66 | 1.44 | 54.39 |
| 6. | 43.61 | 32.08 | 5.14 | 1.44 | 1.11 | 16.94 | 99.87 | 21.79 | 15.90 | 4.37 | 1.39 | 1.82 | 54.73 |
| 7. | 43.63 | 31.15 | 6.01 | 1.54 | 0.85 | 16.86 | 100.04 | 21.88 | 15.48 | 5.13 | 1.49 | 1.39 | 54.63 |
| 8. | 43.80 | 31.19 | 5.29 | 1.46 | 0.98 | 16.82 | 99.51 | 22.08 | 15.59 | 4.51 | 1.41 | 1.16 | 54.80 |
| 9. | 43.93 | 31.17 | 5.58 | 1.76 | 0.90 | 16.80 | 100.14 | 22.05 | 15.51 | 4.76 | 1.69 | 1.48 | 54.51 |
| 10. | 43.96 | 30.36 | 5.61 | 1.48 | 0.96 | 16.96 | 99.33 | 22.07 | 15.11 | 4.79 | 1.43 | 1.57 | 55.03 |
| 11. | 44.07 | 31.02 | 5.57 | 1.66 | 0.85 | 16.87 | 100.04 | 22.11 | 15.43 | 4.75 | 1.60 | 1.39 | 54.72 |
| 12. | 44.15 | 30.13 | 5.57 | 1.69 | 0.87 | 16.55 | 98.96 | 22.40 | 15.16 | 4.81 | 1.90 | 1.43 | 54.30 |
| 13. | 44.16 | 30.13 | 5.79 | 1.61 | 0.94 | 16.69 | 99.32 | 22.32 | 15.10 | 4.89 | 1.56 | 1.54 | 54.50 |
| 14. | 44.70 | 30.57 | 5.93 | 1.71 | 0.80 | 16.63 | 100.34 | 22.53 | 15.27 | 5.09 | 1.65 | 1.31 | 54.15 |
| 15. | 46.17 | 29.59 | 5.66 | 1.09 | 0.95 | 16.62 | 100.08 | 23.36 | 14.83 | 4.86 | 1.06 | 1.54 | 54.35 |
| 16. | 46.17 | 29.37 | 4.99 | 1.43 | 0.92 | 16.31 | 99.19 | 23.64 | 15.04 | 4.34 | 1.40 | 1.53 | 54.05 |
| 17. | 46.51 | 29.27 | 5.29 | 1.41 | 0.87 | 15.99 | 99.34 | 24.05 | 15.00 | 4.65 | 1.39 | 1.46 | 53.45 |
| 18. | 44.15 | 30.60 | 5.67 | 1.59 | 0.93 | 16.69 | 99.63 | 22.29 | 15.30 | 4.86 | 1.54 | 1.52 | 54.49 |

1 = stoichiometric cosalite ($Pb_2Bi_2S_5$), 2 - 17 = from Dunjeon gold mine,

18 = mean value from No. 2 to No. 17.

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*Department of Geological Sciences*
*Seoul National University*
*Seoul, Korea*
CHAN HEE LEE
HEE IN PARK

*Department of Geology*
*University of Maryland*
*College Park, Maryland, U.S.A.*
LUKE L. Y. CHANG

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# The breakdown of Zn-rich staurolite in a metabasite from the Betic Cordillera (SE Spain)

STAUROLITE is a characteristic mineral in medium and upper metamorphic grade rocks, most commonly found in metapelites; it has been reported occasionally in other rock types such as metabasites (Gibson, 1978; Moeen, 1991). Some natural staurolite specimens have a remarkable Zn-content, with up to 8 wt.% ZnO (Spry and Scott, 1986). Between the staurolite Zn-content and the *PT* stability field of this mineral, some empirical relationships have been proposed (Guidotti, 1970). He has shown that at higher metamorphic grades the Zn-content stabilizes the staurolite. In the present study, a staurolite with exceptionally high Zn-content in a metabasite sample with medium to low metamorphic grade assemblages is reported. Its textural relationships and transformation products to mineral assemblages rich in Zn are described also.

The metabasite outcrop studied (now amphibolites and amphibole-mica schists) belongs to the Bédar-Macael unit, from the Lubrín area (longitude 2°51′W, latitude 37°11′N). This is the uppermost unit of the Nevado-Filabride Complex, the lowest complex of the Alboran Domain in the Betic Cordillera (SE Spain) (García-Dueñas *et al.*, 1988). In the study area, two lithologic series can be distinguished in the Bédar-Macael unit. The lower one (to which a Paleozoic age has been attributed) consists essentially of graphite metapelites (quartz–mica–kyanite–chloritoid–garnet–staurolite schists), whereas the upper series (probably Permo–Triassic in age) is made up of albite metapelites (quartz–mica–albite–chloritoid–garnet–kyanite schists) and marbles at the top. Within the latter lithologic assemblage, and preferentially along the contact between metapelites and marbles, a continuous band of metabasites with a maximum thickness of 200 m crops out. An Upper Jurassic age for the mafic protoliths was established by Hebeda *et al.* (1980).

The metabasites of the Bédar-Macael unit underwent alpine metamorphism characterized by a clockwise metamorphic evolution, in which three main mineral growing episodes can be distinguished. (1) A first episode under eclogite facies and blueschist facies (12 ± 2 kbar, 400 ± 50 °C); (2) a syn-kinematic retrograde episode under amphibolite facies, with a decrease in *P* at constant *T* (up to 5 kbar, 350 °C); and (3) a post-kinematic retrograde episode under greenschist facies, with a simultaneous decrease of *P* and *T* (Nijhuis, 1964; Bakker *et al.*, 1989; Soto, 1991).

Amphibolites together with amphibole–mica schists are the most common rock types in metabasites of the Bédar-Macael unit. Intercalated marbles, calcareous mica schist and quartzite veins appear in minor amounts. The mineralogy of the metabasites is characterized by several types of amphiboles (crossite, barroisite and minor Mg-hornblende), epidote, plagioclase (mean composition $Ab_{98}$), garnet (almandine > grossular > pyrope > spessartine), and opaque minerals (hematite-ilmenite intergrowths and magnetite; Nijhuis, 1964).

Metabasites exhibit a well-developed syn-kinematic schistosity generated during the second metamorphic event (amphibolite facies). A