# Au-Ag-Pb-Sn-Sb PHASES IN NATURE AND EXPERIMENTS

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Beside (Au,Ag) natural alloys some gold compounds with metals and "semi-metals" can be found in nature. Except tellurides of Au and Au-Ag they are mainly relatively rare minerals aurostibite ($AuSb_2$), maldonite ($Au_2Bi$), hunchunite ($Au_2Pb$) [1], anyuiite ($AuPb_2$) [2], and yuanjiangite (AuSn) [3] (Table 1).

**Table 1**

| Mineral | Formula | Admixtures | Symmetry and cell parameters (Å) | Str.type |
|---|---|---|---|---|
| Aurostibite | $AuSb_2$ | | Cub., Pa3, a=6.659 | $FeS_2$ (pyrite) |
| Hunchunite | $Au_2Pb$ | Ag, Cu, Hg | Cub., Fd3m, a=7.933 | $Cu_2Mg$ |
| Anyuiite | $AuPb_2$ | Sb | Tetr., I4/mcm, a=7.39, c=5.61 | $CuAl_2$ |
| Maldonite | $Au_2Bi$ | | Cub., Fd3m, a=7.958 | $Cu_2Mg$ (?) |
| Yuanjiangite | AuSn | | Hex., $P6_3/mmc$, a=4.316, c=5.51 | NiAs |

The multi-component Au-intermetallide with the composition ~$Au_6Pb_5Sb_3$ [$Au_3(Pb,Sb)_4$], was found in the gold deposit Tetrem (SW Ghana, some 30 km N of Takoradi). This find could be an interesting supplement to the gold mineralogy because this phase contains Pb, Sb, Bi, and Hg.

The mineral is found in quartz veins where it is closely intergrown with: a) free gold (containing up to 7.2 Wt% Ag, up to 5.7 Wt% Hg), and b) with hunchunite, $Au_2Pb$ [1] (Fig.1). Such intergrowths are similar to the solid solution decomposition ones. Some parts of native gold contain tiny grains (<5-10 μm) of aurostibite, $AuSb_2$, and of altaite, PbTe.

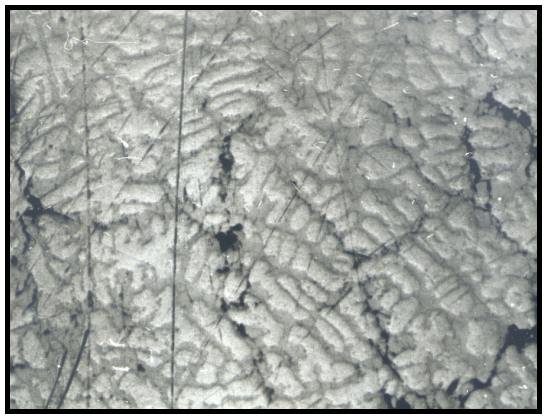

**Fig.1.** White grains of Au-Pb-Sb(Sn) mineral within the matrix of hunchunite (grey).

According to x-ray powder data (Gandolfi, Ø 57.3, λFe) the mineral differs from all known binary Au compounds. Based on the preliminary indexing (TREDAT) the tetragonal cell [a=b= 8.401(2), c=8.239(1) Å] could be proposed for this mineral.

In order to investigate the new mineral phase in detail the synthesis of its analogue has been carried out from the melt using the Kullerud method. The starting compositions covered the part of the multi-component Ag-Pb-Bi-Sb system corresponding to known Au minerals and their associations.

The ore microscopy shows that all samples synthesized are characterized by close pseudographic phase intergrowths. The grain dimensions of phases mainly do not exceed first microns, and very rare are up to 20 μm (Fig.2, 3). This fact caused problems with the interpretation of microprobe data (SX-500). Therefore the phase determination, the chemical composition of phases, and the trace element contents were studied also using the scanning electron microscope and energy-dispersive analysis (analytical complex "JSM-5300+LINK ISIS").

The series of compounds was synthesized: (Au,Ag), $Au_2Pb$ (hunchunite), $AuPb_2$ (anyuiite), $Au_2PbSn$, $Au_3(Pb,Sb,Sn)_4$ (the new mineral phase), AuSn (yuanjiangite), ~$Au_{10}Sn$, ~$Au_6Sn$. Depending on the starting composition the different associations are obtained (Table 2). The original structures of synthesized materials presented by skeletal or dendrite-like crystals of one phase in the matrix of another one (Fig.2, 3) could be formed during the decomposition of high-temperature solid solution.

The synthesized binary compounds of Au are rich in Ag (>11 Wt%). The concentration of all other element except Pb does not exceed the first Wt.% (Table 2). It is not completely clear what causes so high Pb content in Au and in Au-Sn phases: a) the isomorphous replacement of Sn (Sb) by Pb in the

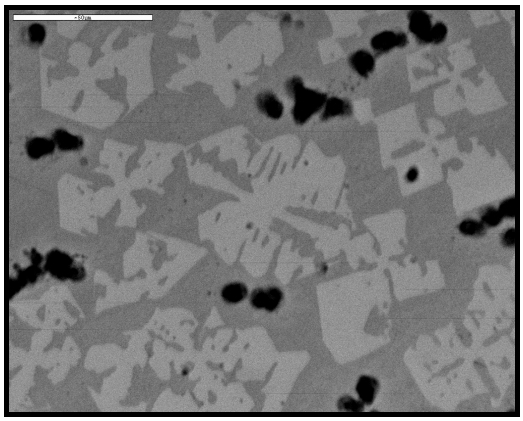

**Fig.2.** Skeletal crystals of $Au_2Pb$ (white) within the $AuPb_2$ matrix. Pol.section. Scale - 50μm.

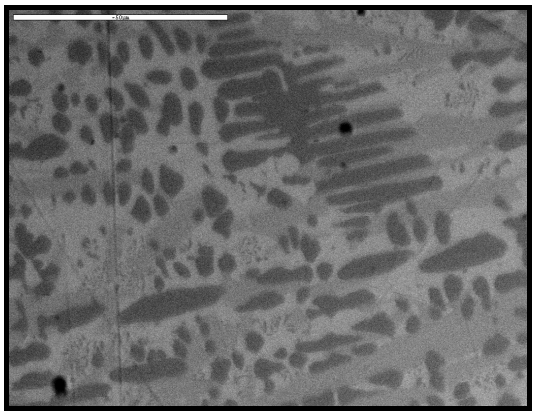

**Fig.3.** Complex intergrowth of AuSn (dark), $Au_2Pb$ (white), and $Au_3(Pb,Sb,Sn)_4$ (grey). Pol.section. Scale – 50 μm.

structure, or b) the tiny inclusions of Au-Pb phases. Now we have no proofs of the second version, but this question needs the additional study.

**Table 2**

| Association | Trace element content (Wt%) [ SEM+EDD] | | | | |
|---|---|---|---|---|---|
| | (Au,Ag) | $Au_2Pb$ | $AuPb_2$ | AuSn | $\sim Au_6Sn$ |
| $Au_2Pb + AuPb_2$ | | | | | Ag – 11.1 |
| $Au_2Pb$ + $Au_2PbSn$ | | | | | |
| $Au_2Pb + AuSn$ | | Sn – 2.65; Sb – 1.29 | | Pb – 8.37; Sb – 5.0 | |
| $Au_2Pb + AuPb_2$ + AuSn | | | | | |
| $AuPb_2 + AuSn$ | | | | | |
| $Au_2Pb + AuSn$ + $Au_3(Pb,Sb,Sn)_4$ | | Sn – 4.92; Sb – 1.43 | | Pb – 12.59; Sb – 5.29 | |
| $Au_2Pb + (Au,Ag)$ | Ag – 8.37; Sn – 5.02 | | | | |
| (Au,Ag) + $\sim Au_6Sn$ | Ag – 6.99 ; Sn – 5.37 | | | | Ag – 6.54 |
| $Au_{10}Sn + \sim Au_6Sn$ | | | | | |
| $\sim Au_6Sn + AuSn$ | | | | | |

It is interesting to note that for all synthesized phases the inverse dependency "(Au+Ag) : (Pb+Sn+Sb) » is observed, but no correlation between the Pb, Sn, Sb concentrations (or their combinations) has been found.

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