

# Some unusual gold and bismuth mineralization at Mardoonganna Hill, Murchison mineral field

by L. Y. Hassan and R. M. Clarke<sup>1</sup>

## Abstract

A suite of unusual secondary bismuth minerals is associated with gold mineralization in amphibolite at Mardoonganna Hill, 74 km northwest of Cue in Western Australia. These minerals include bismite, mixite, and an unidentified bismuth–iron silicate. A secondary rare earth–copper arsenate intermediate in composition between agardite-(Ce) and agardite-(La) was also identified. Gold is present as electrum in grains 5–35 µm across. The mineralization has similar bismuth levels as the Juno mine in Tennant Creek. It is possibly related to porphyry intrusions or felsic volcanic activity.

**KEYWORDS:** bismuth, gold, electrum, mixite, bismite, agardite.

## Geological setting

The prospect is in an outlier of Archean greenstones northwest of the Weld Range greenstone belt on BELELE\* (Elias et al., 1982; Fig. 1) near the contact between basalt and dolerite shown on that map sheet. More recent mapping of the outlier (Battle Mountain (Australia) Incorporated, 1995) identified banded iron-formation units within fine- and medium-grained amphibolites intruded by narrow porphyry dykes. Felsic volcanoclastic rocks were mapped southeast of the prospect.

## Introduction

Samples of poorly exposed amphibolite from Mardoonganna Hill (74 km northwest of Cue; Fig. 1), collected by a prospector, Mr Don Caesar, assayed up to 124 ppm gold. When Mr Caesar dollied and panned the samples he obtained a straw-coloured tail, but could see no gold so he submitted samples to the authors for examination.

In hand specimen the host rock appeared dark green with no obvious sign of mineralization apart from some green secondary minerals along thin veinlets and on fracture surfaces. Polished sections of the

specimens were examined using a reflected light microscope and a scanning electron microscope (SEM). An examination of the back-scattered electron image of a polished section under the SEM showed numerous very bright (high average atomic number) grains. Semiquantitative analysis showed that these contained bismuth and Mr Caesar was advised to have the samples assayed for bismuth. The samples assayed up to 8060 ppm bismuth and 5580 ppm copper. Such high bismuth levels are unusual for Western Australia, but are comparable with those at the Juno mine at Tennant Creek in the Northern Territory, where the average grade of ore treated was 76.48 ppm gold; 0.61% bismuth, and 0.42% copper (Large, 1975). Because the mineralization of the sample was so unusual, it was decided to undertake a study of the secondary minerals.

## Host lithology

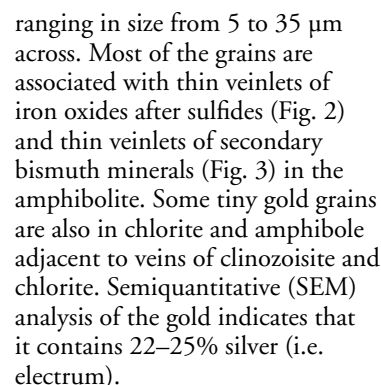
Petrographic examination of the host amphibolite shows that it consists mainly of blue-green hornblende and colourless to green pleochroic chlorite with anomalous blue interference colours, with minor biotite, ilmenite, and quartz. The rock has been completely recrystallized and no primary igneous textures are evident. In the most strongly mineralized samples, the amphiboles have been almost entirely replaced by chlorite and there are veins and segregations of clinozoisite (both minerals with anomalous blue interference colours). Numerous thin veinlets contain iron oxides and secondary ore minerals.

## Nature of the gold

Examination of polished sections under reflected light showed the gold as numerous irregular grains

<sup>1</sup> Chemistry Centre of Western Australia, 125 Hay Street, East Perth, W.A. 6004

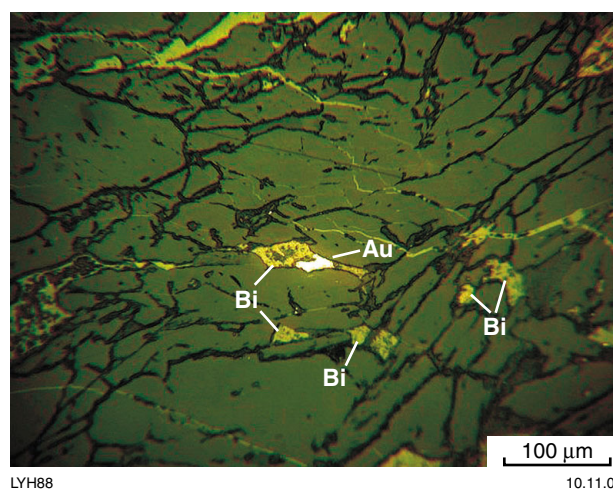
\* Capitalized names refer to 1:250 000 map sheets



## Analytical methods

The samples were examined using X-ray powder diffraction (XRPD) analysis and energy dispersive X-ray analysis (EDXRA) on a scanning electron microscope. The XRPD analyses were performed using  $\text{CoK}\alpha$  (1.7902 Å) radiation on small amounts (of the order of 1 mg or less) of hand-picked sample, pulverized using glass slides, and mounted on low-background quartz plates. EDXRA was performed on rough grains mounted on carbon tape (semiquantitative) and on a polished thin section (quantitative).

Figure 1. Regional geological setting of the Mardoonganna Hill prospect, northwest of the Weld Range greenstone belt on BELELE (1:250 000; after Elias et al., 1982)



**Figure 2. Gold (electrum) grain (Au) associated with iron oxides (FeOx) after sulfides (reflected light)**

*Figure 3. Gold (electrum) grain (Au) with bismite (Bi) along fracture (reflected light)*



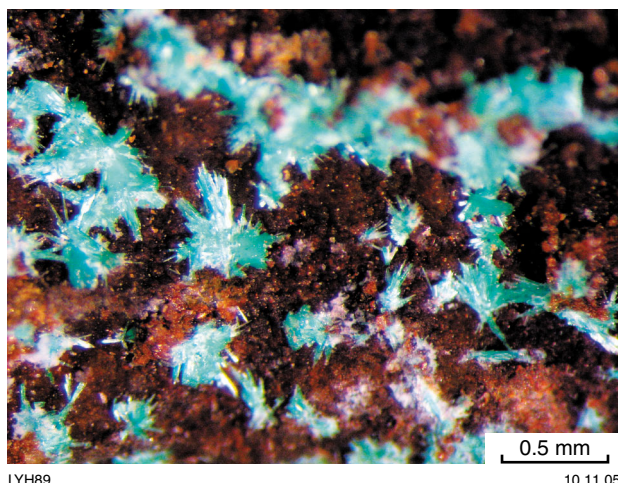


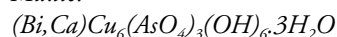
Figure 4. Tufts of fine radiating fibres of mixite on fracture surfaces

### Minerals identified

#### *Bismite:* $\text{Bi}_2\text{O}_3$

Bismite is abundant and forms fracture fillings and interstitial composite grains up to 100  $\mu\text{m}$  across. It is commonly associated with gold–electrum (Fig. 3). A sample assayed 94.6%  $\text{Bi}_2\text{O}_3$ , 0.6%  $\text{FeO}$ , and 0.5%  $\text{CaO}$ .

#### *Mixite:*



Mixite forms bluish-green rosettes (up to 0.5 mm across) and tufts of fine radiating fibres on fracture

surfaces (Fig. 4). It also forms acicular crystals up to 350  $\mu\text{m}$  long and several microns wide infilling veinlets that are progressively lined by a bismuth–iron silicate and a copper silicate (Fig. 5), indicating that mixite was formed late in the paragenetic succession. EDXRA analyses of the mixite (Table 1) indicate that it is compositionally intermediate between ideal mixite ( $\text{BiCu}_6(\text{AsO}_4)_3(\text{OH})_6 \cdot 3\text{H}_2\text{O}$ ) and zálefite ( $\text{CaCu}_6(\text{AsO}_4)_3(\text{OH})_6 \cdot 3\text{H}_2\text{O}$ ). A back-scattered electron image showed apparent zonation in the mixite crystals, with a brighter core containing the highest  $\text{Bi}_2\text{O}_3$  and

lowest  $\text{CaO}$  content. The empirical structural formula derived from the average of three analyses of the Mardoonganna Hill material is:  $(\text{Bi}_{0.60} \text{Ca}_{0.40})_{1.00} (\text{Cu}_{5.75} \text{Ca}_{0.26} \text{Fe}_{0.06})_{6.07} (\text{AsO}_4)_{2.93} (\text{OH})_6 \cdot 3\text{H}_2\text{O}$ . It is based on the currently accepted ideal formula for this mineral (Anthony et al., 2000) and assumes six hydroxyl ions and three molecules of water with a total of 10 metal cations.

X-ray powder diffraction gave the main lattice spacings ( $\text{\AA}$ ) and intensities as follows: 11.8 (100), 2.95 (23), 4.46 (19), 2.57 (19), 2.71 (16), 3.56 (14), 3.27 (13), 2.46 (11). These data agree closely with powder diffraction file card number 13-0414, mixite from the Anton mine from Black Forest in Germany as well as with data obtained from a reference specimen of mixite from Schneeberg in Germany, kindly supplied by Dr. Alex Bevan of the Western Australian Museum (Specimen MDC 5856).

#### *Agardite-(Ce):* $(\text{Ce}, \text{La}, \text{Ca}, \text{Bi})\text{Cu}_6(\text{AsO}_4)_3(\text{OH})_6 \cdot 3\text{H}_2\text{O}$

An apple-green coating on a single specimen of amphibolite (Fig. 6) has been identified as agardite-(Ce). X-ray powder diffraction gave the main lattice spacings ( $\text{\AA}$ ) and intensities as follows: 11.8 (100), 4.45 (21), 3.56 (20), 2.46 (19), 2.94 (18), 3.27 (14), 2.57 (12), 2.71 (10). The

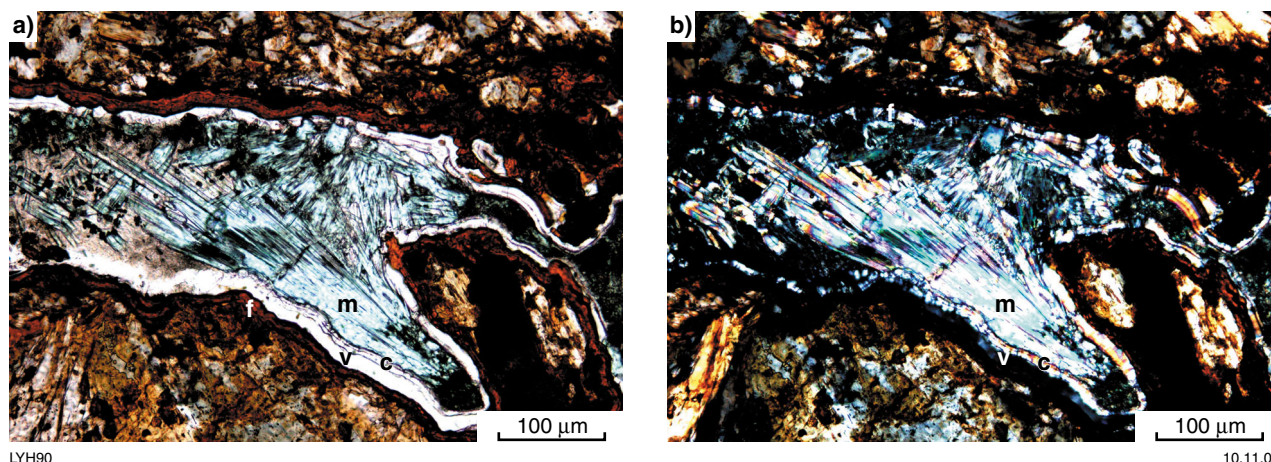


Figure 5. Acicular crystals of mixite (m) infilling veinlets that are progressively lined by a brown bismuth iron silicate (f) and a copper silicate (c): a) plane-polarized light; b) cross-polarized light. Note that there is a void (v), possibly caused during sample preparation, between the copper silicate and bismuth–iron silicate

Table 1. Mixite chemistry

Assay	1	2	3	4	5	6	7	8
CuO	46.48	44.43	43.58	42.07	42.13	42.48	44.23	41.04
As <sub>2</sub> O <sub>3</sub>	29.10	27.96	28.01	27.67	26.91	29.17	29.51	29.64
Bi <sub>2</sub> O <sub>3</sub>	12.03	11.72	17.29	14.13	11.94	19.10	12.25	20.03
CaO	4.24	4.45	2.24	2.53	3.24	1.55	0.83	0.00
FeO	0.53	0.33	nd	nd	nd	0.53	1.52	0.00
SiO <sub>2</sub>	nd	nd	nd	0.81	1.51	nd	nd	0.00
P <sub>2</sub> O <sub>5</sub>	nd	nd	nd	nd	nd	nd	1.05	0.00
H <sub>2</sub> O	na	na	na	na	na	na	11.06	9.29
<b>Total</b>	<b>92.38</b>	<b>88.90</b>	<b>91.12</b>	<b>87.21</b>	<b>85.73</b>	<b>92.83</b>	<b>100.45</b>	<b>100.00</b>

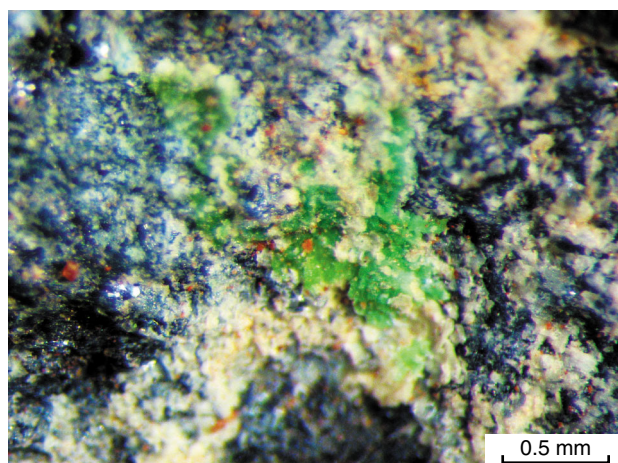
**NOTES:** Assays 1–3 are separate spot assays on mixite crystal in vein within polished thin section from Mardoonganna (GSWA 116720)  
 Assays 4–5 are semiquantitative assays on rough grains of mixite from Mardoonganna  
 Assay 6 is a semiquantitative assay on rough grain of mixite from Schneeberg, Saxony (kindly loaned by the West Australian Museum)  
 Assay 7 is a published analysis of mixite from the type location at Jáchymov, Czech Republic (Anthony et al., 2000)  
 Assay 8 is ideal mixite (BiCu<sub>6</sub>(AsO<sub>4</sub>)<sub>3</sub>(OH)<sub>6</sub>·3H<sub>2</sub>O)  
 nd not detected  
 na not analysed

X-ray powder diffraction pattern is indistinguishable from mixite, but semiquantitative microanalysis (Table 2) indicates relatively low bismuth content (~1% bismuth oxide) and about 3 and 2%, respectively, of cerium and lanthanum oxides. The agardite is thus intermediate between agardite-(Ce) (ideal formula: (Ce,Ca)Cu<sub>6</sub>(AsO<sub>4</sub>)<sub>3</sub>(OH)<sub>6</sub>·3H<sub>2</sub>O) and agardite-(La) (ideal formula: (La,Ca)Cu<sub>6</sub>(AsO<sub>4</sub>)<sub>3</sub>(OH)<sub>6</sub>·3H<sub>2</sub>O).

#### Copper silicate (unidentified)

A copper silicate forms 3–5 µm colourless selvages to veinlets of

mixite (Fig. 5a). It has moderate birefringence and cross-fibre structure. Microanalysis at two spots gave MgO (0.5, 0.5%), Al<sub>2</sub>O<sub>3</sub> (2.3, 3.3%), SiO<sub>2</sub> (45.9, 54.8%), CaO (1.1, 1.0%), FeO (0.3, 0.5%), and CuO (26.6, 27.9%). The mineral is possibly chrysocolla — a hydrogel that has a wide range in composition. However, the silica content is higher and the copper content lower than that reported by Klein and Hurlbut (1993) for chrysocolla (37.9–42.5% SiO<sub>2</sub>, 32.4–42.2% Cu). Extraction of the mineral for XRPD analysis was not possible.



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Figure 6. Agardite-(Ce) (apple-green mineral) surrounded by yellow smectite on fracture surface of amphibolite

#### Amorphous or cryptocrystalline iron–bismuth–copper silicate (unidentified)

A brown colloidal mineral forms selvages to veinlets of mixite (Fig. 5) and interstitial patches up to 0.5 mm across. The back-scattered electron image showed that the material was zoned with brighter material on the inner and outer edges. Microanalysis of the inner zone gave FeO (57.1%), Bi<sub>2</sub>O<sub>3</sub> (3.1%), CuO (4.1%), Al<sub>2</sub>O<sub>3</sub> (3.5%), SiO<sub>2</sub> (13.7%), TeO<sub>2</sub> (0.6%), and CaO (0.2%). The brighter zones contained more Bi<sub>2</sub>O<sub>3</sub> (5.3%) and TeO<sub>2</sub> (1.19%) and less Al<sub>2</sub>O<sub>3</sub> (2.8%) and FeO (54.6%). An X-ray diffraction pattern yielded a single very weak peak with a d-spacing of 8.4 Å. No minerals with these characteristics are known.

#### Other minerals

Semiquantitative microanalysis led to the identification of tiny blebs of pyrite, chalcopyrite, and bismuthinite within silicates.

### Discussion and conclusions

The gold mineralization at Mardoonganna Hill is unusual for Western Australia because it is associated with an abundance of secondary bismuth minerals. Bismite is the most abundant of these minerals and probably accounts for the straw-coloured tail on panning. A small amount of bismite has previously been reported from Western Australia in association with wolframite in a quartz reef at Ora Banda (Simpson, 1948) and in the Londonderry pegmatite at Coolgardie (Cross, 1993). An unidentified bismuth–iron silicate is also common at Mardoonganna.

Mixite was found on fracture surfaces and in veinlets. The only other confirmed mixite in the State is from the Nifty deposit (Downes et al., 2002). Clarke (1979) reported mixite from diggings in black shale in the Widgiemooltha area on the basis of an XRD powder pattern, but noted that samples from the pit assayed less than 5 ppm Bi. Because the XRD pattern of mixite is similar to that of agardite, it is probable that the sample was actually agardite or another member



**Table 2. Agardite chemistry**

Assay	1	2
CuO	45.08	45.76
As <sub>2</sub> O <sub>3</sub>	30.85	42.53
Bi <sub>2</sub> O <sub>3</sub>	1.19	1.54
CaO	3.61	3.41
FeO	1.80	1.06
SiO <sub>2</sub>	13.26	3.61
La <sub>2</sub> O <sub>3</sub>	2.08	2.81
Ce <sub>2</sub> O <sub>3</sub>	3.29	4.01
H <sub>2</sub> O	na	na
<b>Total</b>	<b>104.10</b>	<b>104.73</b>

**NOTES:** 1–2: semiquantitative analyses on rough grains of agardite (some adjacent silicate may be included)  
na not analysed

of this family. Elsewhere in Australia, mixite has been reported from the Mount Malvern lead–silver mine in the Mount Lofty Ranges of South Australia (Kolitsch and Elliot, 1999).

Agardite identified in a specimen from Mardoonganna Hill is intermediate in composition between agardite-(Ce) and agardite-(La). Most agardite previously reported from Australia is agardite-(Y), such as as Mount Malvern in South Australia (Kolitsch and Elliot, 1999) and Broken Hill (Birch and van der Heyden, 1997). However, agardite-(Ce) has been reported from Telfer (Downes et al., 2002). Intermediate varieties of agardite, including some containing up to 3.96% bismuth have been recorded from Sardinia in Italy (Olmi et al., 1991).

The bismite was identified in veinlets and microfractures and is probably replacing bismuthinite or another bismuth mineral. The electrum is closely associated with the bismite and appears to be primary. The mixite and agardite are late in the paragenetic succession and have probably resulted from weathering of sulfides, sulfosalts, or telurides and were deposited along near-surface fractures as described by Kolitsch and Elliot (1999) and Downes et al. (2002).

There is possibly some relationship between the primary mineralization and the porphyry intrusions in the area or with the felsic volcanic rocks exposed to the southeast.

The mineralization is similar to the epithermal Proterozoic Juno gold–bismuth deposit at Tennant Creek (Large, 1975) in its high bismuth content, highly fractured nature, and the presence of chlorite as a major alteration mineral, but differs in the lack of abundant iron oxides.

This style of mineralization would be difficult to recognize in the field due to the dark-green colour of the ore as a result of chloritic rather than the more usual sericitic alteration (bleaching) and the lack of quartz veins. The blue-green mixite along fractures is a guide, however, to high gold content.

In addition, there is a good correlation between gold and bismuth indicating that bismuth would be an excellent pathfinder to gold in this area.

### Acknowledgements

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