The purpose of this paper is to characterise the cassiterite and various heavy minerals present in the tailings, amang, mineralised veins and river samples, inclusive of zoning, intergrowths and inclusions, using the EPMA and reflected light microscope with the view of refining the paragenesis of the mineralisation at Tekka. In addition the EPMA was able to differentiate rutile, topaz, xenotime, monazite, tantalite, columbite, wolframite and struvite through X-ray mapping. The EPMA was able to justify the occurrence of fine gold in fractures in cassiterite, wolframite and black tourmaline and identify lesser known minerals like stolzite (PbWO₄), enargite (Cu₃AsS₄) and yttrotungstite [(Ce, Nd, Y)WO₄(OH)₂] and report for the first time in the Tekka area the occurrence of native bismuth, bismuthinite (Bi₂S₃), matildite (AgBiS₂) and mimetite [Pb(AsO₄, PO₄)Cl]. The EPMA was able to identify inclusions of ilmenorutile, tapiolite, arsenopyrite and ilmenite in cassiterite besides confirming that the different colours of tourmaline found at Tekka is a reflection of their different Fe and Mg contents. All the new information on the new mineral species and their related mineral associations have aided in the preparation of a more complete paragenetic sequence of the Tekka xenothermal deposit.

INTRODUCTION

Samples of tailings, amang and hard rocks were collected from different localities in the Tekka area (Hooi, 2002). Samples were collected from the main pit, sand mine area, rivers and Merapoh Mine (Fig. 2). Samples from the river include B2, B3, B4, B5, B6, B7, B8 and D1. Samples from the main pit include X1, X2A, X2B, X3A, X3B, X4A and X4B. Samples X2A, X2B, X3A, X3B, X4A and X4B were collected from 2 different horizons in the main pit area to compare their heavy mineral content. Three samples were sampled in the sand mine namely Z5, Z6 and Z7. Three hard rock samples

METHOD AND MATERIALS

Samples of tailings, amang and hard rocks were collected from different localities in the Tekka area (Hooi, 2002). Samples were collected from the main pit, sand mine area, rivers and Merapoh Mine (Fig. 2). Samples from the river include B2, B3, B4, B5, B6, B7, B8 and D1. Samples from the main pit include X1, X2A, X2B, X3A, X3B, X4A and X4B. Samples X2A, X2B, X3A, X3B, X4A and X4B were collected from 2 different horizons in the main pit area to compare their heavy minerals contents. Three samples were sampled in the sand mine namely Z5, Z6 and Z7. Three hard rock samples
T1, T2 and T3 were collected from the main pit, Merapoh Mine and the eastern side of the Tekka Hill respectively. All the samples other than the hard rock samples were panned to concentrate the heavy minerals for EPMA and microscope study.

In the laboratory, polished sections of the samples were made to study the heavy minerals and their textures under the reflected light microscope. The EPMA (electronprobe microanalyzer) was later used to identify more precisely the heavy minerals, their intergrowths, textures, inclusions, chemical compositions and their abundances. The EPMA at the Geology Department, University of Malaya, is a Cameca SX100 with an energy dispersive spectrometer (EDS) and 4 wavelength dispersive spectrometers (WDS) with 12 analyzing crystals. The EPMA was operated at 20 kV and 20 nA beam current. X-ray mapping on the EPMA was ideal for differentiating the heavy minerals and their intergrowths. The BSE (backscattered electron) image is popularly used to initially differentiate the heavy minerals because it is dependent on atomic number, while the SE (secondary electron) image is best used for studying their morphology (Teh, 2002).

RESULTS AND DISCUSSIONS

The ore microscopy and EPMA study show that the heavy minerals encountered at Tekka include cassiterite, zircon, rutile, xenotime, monazite, wolframite, tantalite, columbite, strûverite, arsenopyrite, enargite, ilmenorutile, tapiolite, galena, native bismuth, bismuthinite, topaz, iron oxide, matildite, mimetite, yttrotungstite, stolzite and gold.

Of these minerals, native bismuth, bismuthinite (Bi₂S₃), matildite (AgBiS₂), mimetite [Pb(AsO₄, PO₄)Cl], yttrotungstite (Ce, Nd, Y)WO₄(OH)₂, and stolzite (PbWO₄), have not been reported before at Tekka. Gold occurrences have been reported by Ingham and Bradford (1960) but samples have never been displayed or described.

The new minerals, bismuth, bismuthinite, enargite, matildite and mimetite were revealed by the EPMA as inclusions and late infilled minerals. With the EPMA, native bismuth was found as ex-solution bodies in arsenopyrite (Fig. 3, Sample T13). Bismuthinite was picked up by the EPMA in the same mineralised vein (Sample T13) associated with inclusions of stannite, sphalerite, chalcopyrite and native bismuth in arsenopyrite (Fig. 3). Enargite was found associated with earlier cassiterite infilling a fracture in arsenopyrite in the same sample. Matildite was found in the same mineralised vein sample associated with arsenopyrite, stannite, chalcopyrite and native bismuth in arsenopyrite (Fig. 3). Matildite is found associated with dark blue tourmaline by the EPMA (Fig. 5). Mimetite has been reported by Ingham and Bradford (1960) from Naga Bisi, near Ipoh.

Stolzite (Fig. 6) and yttrotungstite (Fig. 7) were found in the river concentrates and tailings from the main pit.
Figure 3. BSE image showing ex-solutions of native Bi and inclusions of bismuthinite (Bi$_2$S$_3$) associated with stannite, sphalerite and chalcopyrite (cpy) in arsenopyrite.

Figure 4. BSE image of matildite associated with sphalerite (sph), stannite and arsenopyrite.

Figure 5. BSE image of monoclinic crystals of mimetite (white) associated with dark blue tourmaline.

Figure 6. EDS scan of stolzite (PbWO$_4$) found in river concentrate at Tekka.

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respectively. Stolzite, according to Ingham and Bradford (1960), was found associated with cassiterite and yttrotungstite at Pulai. Yttrotungstite, basically a yttrium-cerium tungstate, was first discovered in Pulai in 1921 (Ingham and Bradford, 1960).

In an amang sample (M4), gold was found in fractures in cassiterite (Fig. 8) and BSE image from the EPMA showed the gold to be very fine, ranging from 2-5 microns. Gold was also found in fractures in wolframite (Fig. 9) in a river concentrate sample (B8), with sizes ranging from 2-25 microns. The EPMA also picked up gold (about 10 microns in size) in a fracture in a black tourmaline sample (T12) (Fig. 10). The occurrences of gold in cracks and

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**Figure 3.** BSE image showing ex-solutions of native Bi and inclusions of bismuthinite (Bi$_2$S$_3$) associated with stannite, sphalerite and chalcopyrite (cpy) in arsenopyrite.

**Figure 4.** BSE image of matildite associated with sphalerite (sph), stannite and arsenopyrite.

**Figure 5.** BSE image of monoclinic crystals of mimetite (white) associated with dark blue tourmaline.

**Figure 6.** EDS scan of stolzite (PbWO$_4$) found in river concentrate at Tekka.
fractures in early cassiterite, wolframite and black tourmaline, show the passage of the later gold-bearing fluids into the cooler portions of the Tekka ore body.

Study of inclusions in cassiterite was made possible with precise determination of compositions by the EPMA. Inclusions found include ilmenorutile [(Ti, Nb, Fe⁺³)₆O₁₆] tapiolite [Fe⁺²(Ta, Nb)₂O₆], arsenopyrite and ilmenite (Fig. 11). Strüverite [(Ti, Ta, Fe⁺³)₆O₁₆] was picked up by the EPMA in *Amang* sample M15 (Fig. 12).

Anyone visiting Tekka will be fascinated by the three colour varieties of tourmaline, namely black, light blue and dark blue. The black variety is normally associated with the granite while the two blue varieties are associated with the schist (Teh, 1969).

An EDS scan on the EPMA shows that the 3 varieties of tourmaline have different Fe, Mg and Ca contents. The black variety has the highest Fe content and lowest Mg content while the light blue variety has the highest Mg

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EPMA study revealed that minerals like monazite, xenotime, zircon and gold are associated with black tourmaline, and all are later, infilling cracks in the tourmaline. Dark blue tourmaline, on the other hand, was found associated with the mineral mimetite.

The EPMA is responsible for the identification of the many new minerals and their associated minerals at Tekka and with this information the paragenesis of the Tekka deposit, a xenothermal deposit (Teh, 1976, 1981), can be duly up-dated (Fig. 14).

X-ray mapping on the EPMA was carried out on the tailings from the main pit and sand mine areas, and amang from Merapoh Mine to determine the abundances, compositions as well as the distribution of the various heavy minerals. X-ray mapping shows that tailings collected from the main pit (Sample X3A) and sand mine (Sample Z7) areas still contain significant amounts of heavy minerals like ilmenite, cassiterite, and topaz (Figs. 15 and 16). Sample X3A has 10.3% cassiterite compared to 3.66% for sample Z7, 7.22% ilmenite compared to 19.5%, 5.15% wolframite compared to 0%, and 33% topaz compared to 9.76% respectively.

The coarser amang sample (M13) from Merapoh Mine at Tekka probably show the original ilmenite (29.3%), cassiterite (14.6%), topaz (6.1%) and wolframite (29.3%).

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Figure 15. EPMA X-ray map of tailings sample from the main pit (X3A) showing significant amounts of ilmenite (Fe, Ti, O), cassiterite (Sn, O) and topaz (Si, Al, F).

Figure 16. EPMA X-ray map of tailings sample from the sand mine (Z7) showing significant amounts of ilmenite (Fe, Ti, O), monazite (Ce, P, O), xenotime (Y, P, O) and zircon (Zr, Si, O).
constituents in amang. With EPMA X-ray mapping it was possible to differentiate the rutile from ilmenite, columbite and tantalite in striivered and the presence of the phosphates, xenotime and monazite, and zircon.

CONCLUSIONS

The study involving reflected light microscopy and the EPMA was able to characterise cassiterite and associated heavy minerals in amang, tailings, mineralized veins and river concentrates in the Tekka area in terms of composition, abundance, inclusions and intergrowths.

Besides confirming the presence of common minerals, namely, cassiterite, ilmenite, iron-oxide, arsenopyrite, stannite, chalcopyrite, pyrite, sphalerite, galena, scorodite, and covellite, the EPMA was able to differentiate enargite, rutile, topaz, xenotime, monazite, tantalite, and columbite, justify the occurrence of gold in cassiterite, wolframite and black tourmaline and identify a number of lesser known minerals like stolzite, striivered and yttrotungstenite and revealed the presence of yet to be reported minerals like native bismuth, bismuthinite, matildite and mimetite in the Tekka area.

EPMA analysis show that the colour of tourmaline found at Tekka is a reflection of different contents of Fe and Mg. Black tourmaline is highest in Fe followed by dark blue and light blue tourmaline while the Mg content is the reverse, being highest in light blue tourmaline and lowest in black tourmaline.

The EPMA also aided the identification of inclusions in cassiterite like ilmenorutile, tapiolite, arsenopyrite and ilmenite.

All this additional information on the numerous mineral species present and their relationships have greatly helped in getting a better picture of the overall paragenesis of the xenothermal Tekka ore deposit which definitely has two generations of cassiterite, an earlier one associated with arsenopyrite, pyrite and wolframite and a later one associated with the sulphides like chalcopyrite, sphalerite and stannite.

The Tekka deposit will continue to be a haven for economic geologists because of its long list of both common and rare mineral occurrences and the relative abundance of topaz and tourmalines (black and blue) not found elsewhere in the country.

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