Geological Society of Malaysia, Bulletin 46
May 2003; pp. 393–399

EPMA characterization of the Fe-Cu-Sn mineralisation at Waterfall Mine, Pelepah Kanan, Johor

TEH GUAN HOE AND LEE HENG POH

Geology Department
University of Malaya
50603 Kuala Lumpur

Abstract: The electronprobe microanalyser (EPMA) is used, for the first time locally, to characterise the Fe-Cu-Sn mineralisation at the Waterfall Mines, Pelepah Kanan, Johor.

Evidences from the field, reflected light microscopy and EPMA studies show that the mineralisation at Pelepah Kanan is essentially a replacement body within a calc-silicate sequence or skarn of early magnetite-cassiterite-fluorite-quartz (Fe-Sn) mineralisation that is intruded by a later phase of copper mineralisation and that both these were later cut by an even later hydrothermal cassiterite-K-feldspar-quartz vein swarm along fissures, joints and faults.

The EPMA was also instrumental in identifying a number of new minerals that have yet to be reported from Pelepah Kanan and they include native bismuth, tennantite (Cu_3AsS_3), wittichenite (Cu_3BiS_3), cuprite (Cu_2O), native Cu and gold.

The variable pinkish nature of the feldspars in the cassiterite-K-feldspar-quartz veins was confirmed to be due to the alteration of Fe-Mn-O material infilling cleavages in the feldspars. In addition EPMA mapping of the dark bands in highly pleochroic cassiterites show that they contain higher amounts of Fe.

Finally EPMA mapping of tailings samples show that they are worth reassessing as a large portion of them still have high iron oxide contents (80-90%).

Abstrak: Peralatan EPMA (electronprobe microanalyzer) digunakan, kali pertama secara tempatan, untuk pencirian pemineralan Fe-Cu-Sn di Waterfall Mine, Pelepah Kanan, Johor.

Bukti-bukti lapangan, kajian mikroskopi cahaya terpantul dan EPMA menunjukkan bahawa pemineralan di Pelepah Kanan adalah jasad penggantian didalam jujukan kalk-silikat atau skarn yang mengandungi pemineralan awal magnetit-kasiterit-fluorit-kuarza yang direjahkan kemudian oleh pemineralan tembaga dan akhirnya kedua-dua pemineralan ini dipotong oleh telerang-telerang hidroterma kasiterit-K-feldspar-kuarza yang lebih lewat yang isikan fisur, kekar, dan sesar.

EPMA juga peralatan yang menentukan beberapa mineral baru yang belum dilaporkan di Pelepah Kanan, iaitu bismut asli, tennantit (Cu_3AsS_3), wittichenit (Cu_3BiS_3), cuprit (Cu_2O), tembaga asli dan emas.

Warna merah jambu feldspar didalam telerang kasiterit-K-feldspar-kuarza disahkan oleh kajian EPMA dihasilkan oleh perubahan bahan Fe-Mn-O khususnya oksida besi yang isikan ira-ira feldspar.

Kajian pemetaan EPMA menunjukkan bahawa jalur-jalur gelap didalam kasiterit yang amat pleokroik disebabkan oleh kandungan Fe yang lebih tinggi.

Akhirnya pemetaan EPMA sampel tailings menunjukkan bahawa mereka harus dikajikan semula oleh sebab bahagian besar mereka masih mengandungi oksida besi yang tinggi (80-90%).

INTRODUCTION

The purpose of this paper is the harnessing of the EPMA (electronprobe microanalyzer) to characterise the Fe-Cu-Sn mineralisation at the Waterfall Mine, Pelepah Kanan, Johor.

Since the discovery in 1901 by the English geologist Captain Snow (Abdullah Hasbi Hassan *et al.*, 1981) and because of its unique mineralisation, the area has attracted various local and international workers (Willbourn, 1936; Roe, 1941; Burton, 1959; Grubb and Hamaford, 1966a, 1966b; Kee Thuan Moore, 1966; Bean, 1969; Ganesan, 1969, 1976; Khoo Han Peng, 1969; Cheng Eng Choon, 1975; Yeap Ee Beng, 1982; Nor Saawaludin Mohd. Nor, 1983; Zubaidi Abbas, 1983; Chu Ling Heng *et al.*, 1984; Wan Fuad Wan Hassan *et al.*, 2000; and Adong Laming, 2001; Lee, 2002).

The mine area is bounded by longitudes 103°50'5"E and 103°50'20"E and latitudes 1°49'50"N and 1°50'20"N covering an area approximately 30 km^2 (Fig. 1).

The main rock type in the area is a calc-silicate hornfels which has been intruded by the Lower Triassic porphyritic biotite granite and associated microgranite and aplite (Yeap, 1982) which are structurally controlled (Wan Fuad Wan Hassan *et al.*, 2000) (Fig. 2).

METHOD AND MATERIALS

Field mapping was carried out taking into careful consideration the relationships between the iron, copper and tin mineralisations. In the laboratory, thin and polished sections of the rock types, ore minerals, iron ore and tailings, were prepared for both reflected microscopy (using a Leitz Laborlux microscope) and EPMA study.

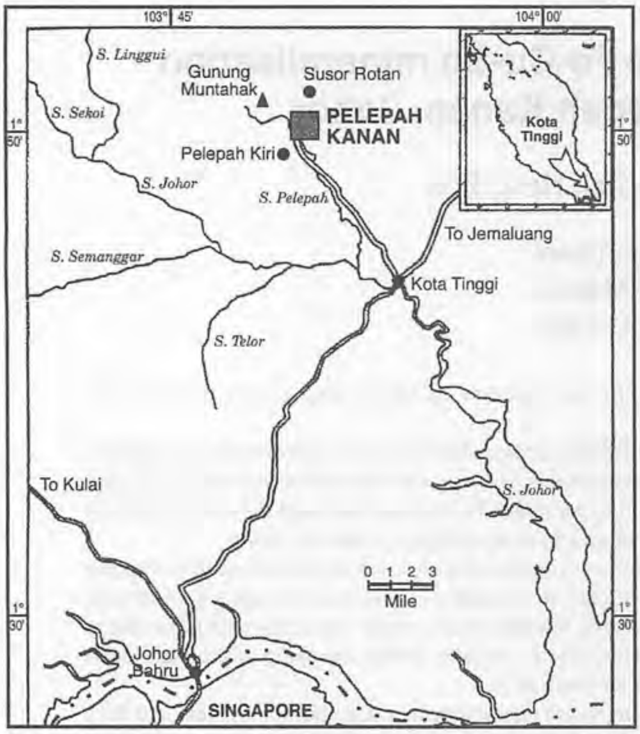

Figure 1. Location of the Pelapah Kanan area.

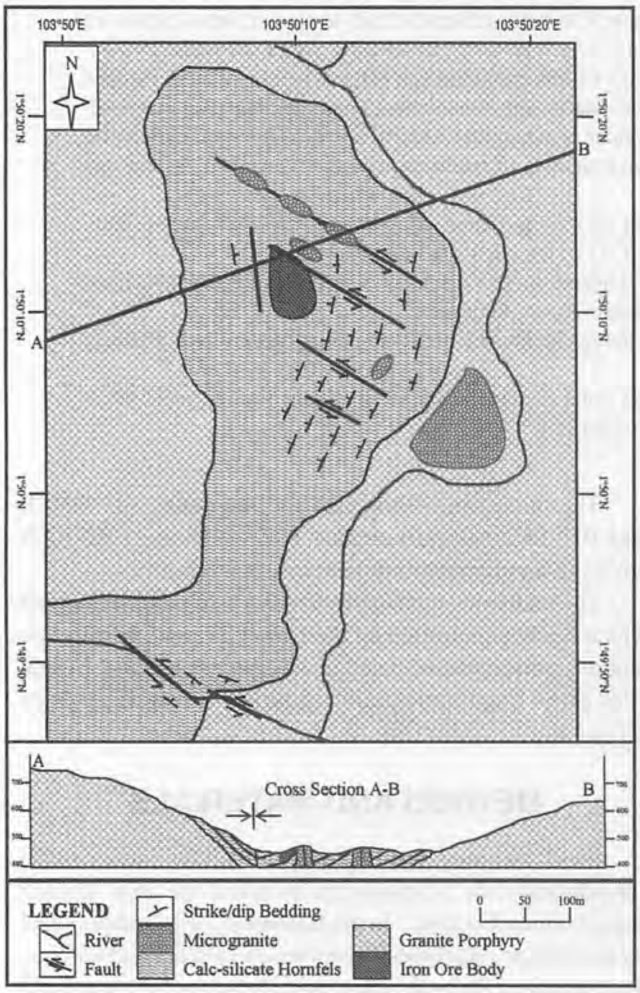

Figure 2. Geology of the Waterfall Mine, Pelepah Kanan (after Adong Laming, 2001).

The EPMA at the Geology Department, University of Malaya, is a Cameca SX100 fully automated with four wavelength dispersive spectrometers (WDS), 12 analysing crystals, and a PGT energy dispersive spectrometer (EDS). The EPMA was operated at 20 kV and 20 nA beam current. The backscattered electron (BSE) image was widely used to differentiate the ore minerals and X-ray mapping was performed to show the distribution of the various elements (Teh, 2002).

RESULTS AND DISCUSSIONS

Earlier studies of the Waterfall Mines, Pelapah Kanan concentrated mainly on the Fe-Sn mineralisation (Burton, 1959; Bean, 1969; Khoo, 1969; Ganesan, 1969; Cheng, 1975; Hosking, 1973; Yeap, 1982; Nor Saawaludin Mohd. Nor, 1983) whilst Wan Fuad *et al.* (2000) reported copper mineralisation in the Pelepah Kanan area having porphyry copper features and associated wallrock alterations.

After careful field investigations followed by laboratory studies, the authors support Hosking's (1973) opinion that the Fe-Sn and Cu mineralisations developed as a replacement body within a calc-silicate sequence or skarn which is associated with an even later swarm of stanniferous veins. However, the initial Fe-Sn mineralisation is essentially magmatic, intrusive (and possibly extrusive too) with rhythmic bands (wrigglites) of vesicular magnetite with fine cassiterite, fluorite (CaF_2) and calc-silicates (Fig. 3). This is followed by the primary copper mineralisation of copper sulphides, cuprite and native Cu which is essentially intrusive and in places flowing over the semi-consolidated earlier Fe-Sn mineralisation as evidenced by field observations of load structures of the copper-rich magma over the Fe-Sn mineralisation (Fig. 4). The copper mineralisation is easily recognised by the formation of the colourful secondary covellite, malachite and azurite, in particular in the area of incipient copper mineralisation of garnetiferous hornfels while the Fe-Sn mineralisation, on

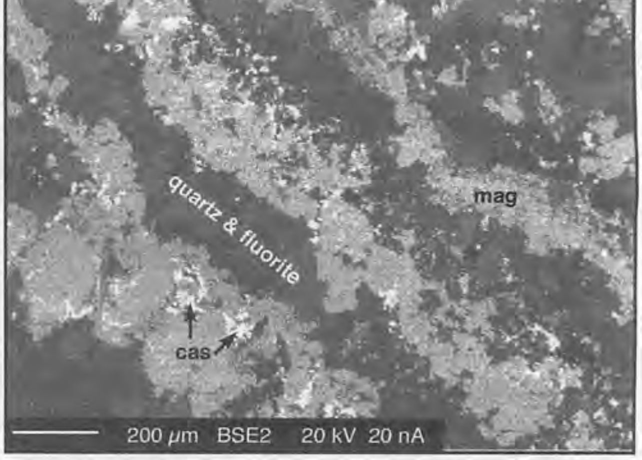

Figure 3. EPMA BSE image showing rhythmic bands of magnetite (mag) with cassiterite (cas), alternating with quartz and fluorite.

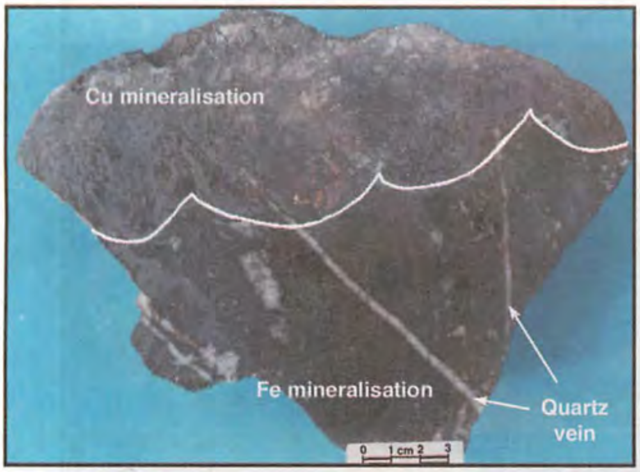

Figure 4. Handspecimen showing load structure of copper mineralisation over earlier iron mineralisation cut by late cassiterite-bearing quartz veins.

Figure 5. Cassiterite-K-feldspar-quartz veins infilling fissures and joints in calc-silicate hornfels.

the other hand, has been extensively altered to goethite and martite.

The earlier Fe-Sn and copper mineralisations are then cut by the much later hydrothermal cassiterite-K-feldspar-quartz veins or veinlets that have infilled fissures, joints or faults (Fig. 5).

EPMA studies have led to the discovery of a number of minerals that have not yet been mentioned at Pelepah Kanan, namely native Bi (Fig. 6), tennantite (Cu_3AsS_3) (Fig. 7), wittichenite (Cu_3BiS_3) (Fig. 8), associated cuprite (Cu_2O), native Cu (Fig. 9) and gold (Fig. 10).

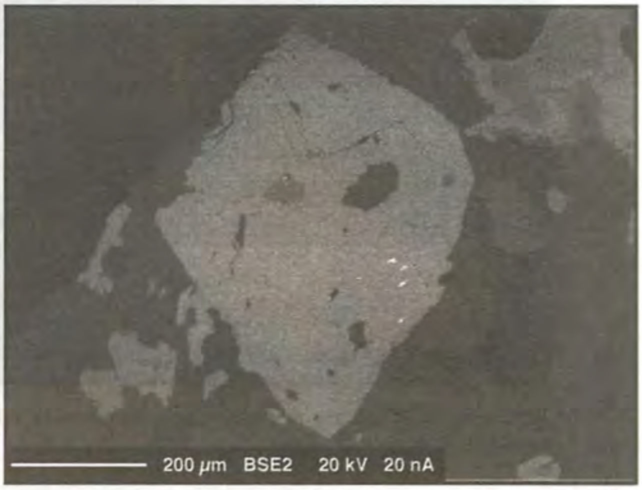

Figure 6. BSE image showing native Bi inclusions (white) in arsenopyrite.

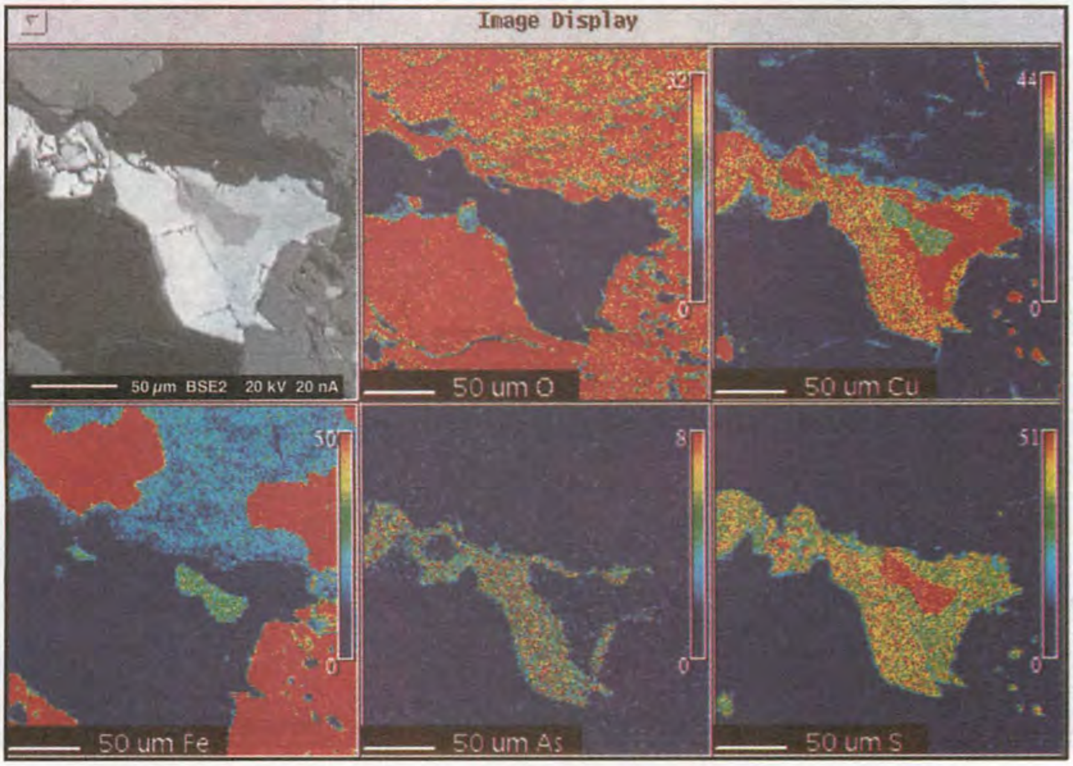

Figure 7. EPMA X-ray mapping showing the presence of tennantite (Cu, As, S) associated with chalcopyrite (Cu, Fe, S) and covellite (Cu, S).

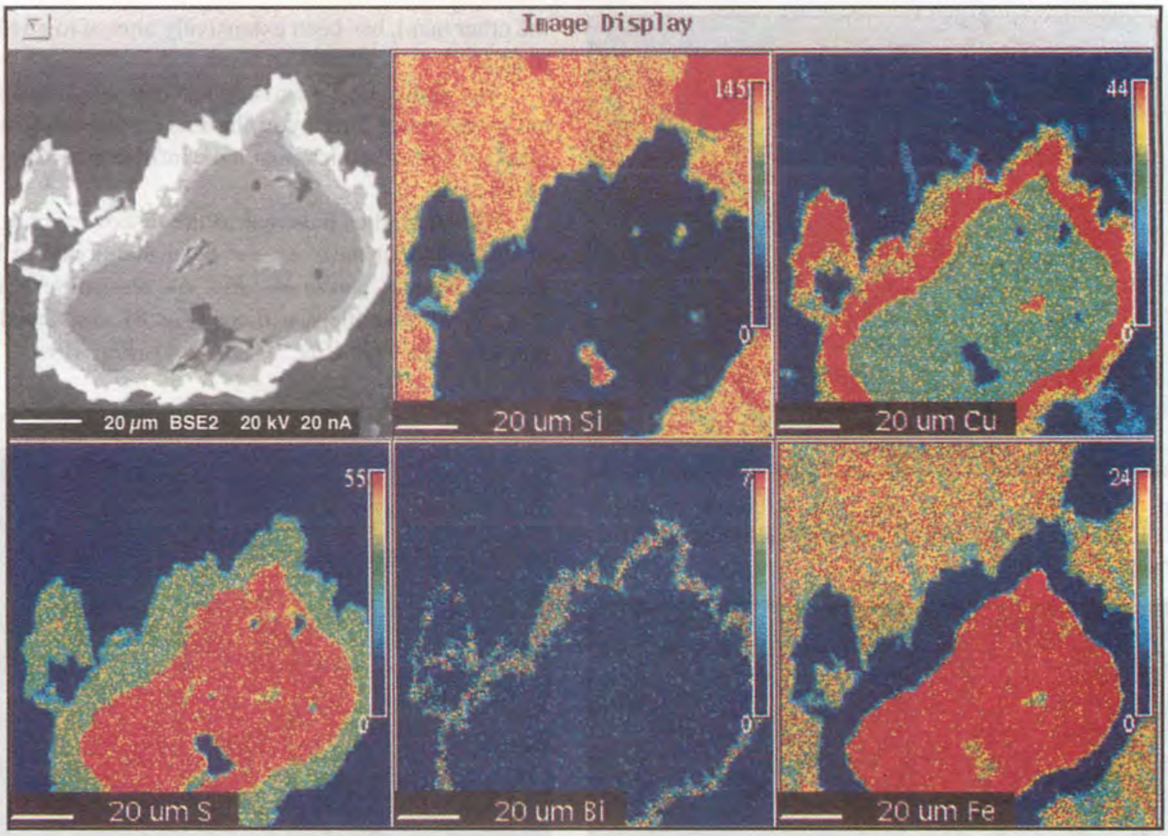

Figure 8. EPMA X-ray map showing wittichenite (Cu, Bi, As) rimming covellite (Cu, S) with core of chalcopyrite (Cu, Fe, S).

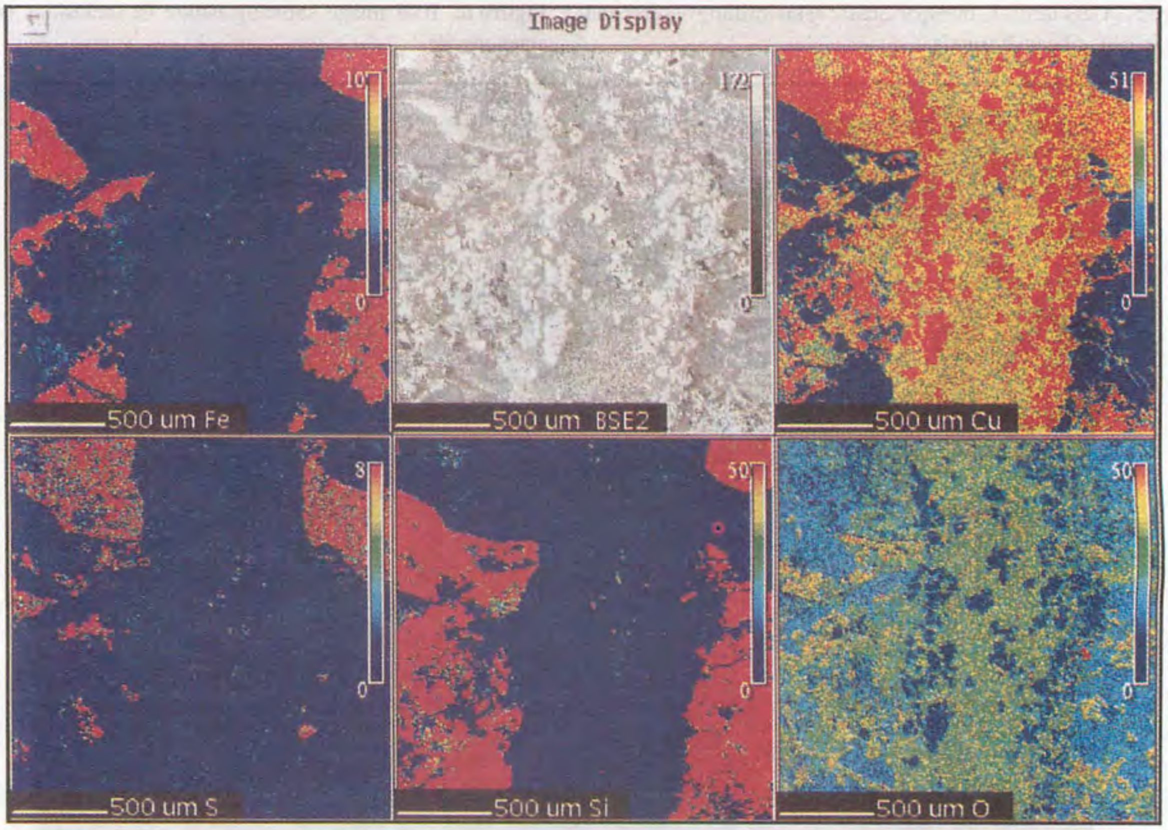

Figure 9. EPMA X-ray map showing native Cu, associated with cuprite (Cu, O) in fracture in calc-silicate hornfels (Si, Al, O).

Table 1. Abundance of minerals (vol. %) and population of the grain sizes in tailings, at Waterfall Mine, Pelepah Kanan, Johor.

Mineral \ Sample	CN1-L1	CN1-L2	CN1-L3
Iron oxide	81.48	53.33	90.67
Cassiterite	17.04	1.33	0.00
Psilomelane	0.00	0.00	1.33
Fe-Ca-Al-Si-O	0.00	8.67	0.00
Quartz	1.48	36.67	8.00
Total:	100.00	100.00	100.00
Size Population (mm)			
Coarse	0.4–0.5	0.4	0.5–0.7
Medium	–	–	0.2
Fine	0.1	0.1	0.1

With careful field observations coupled with mineral relationship determinations from microscopic and EPMA studies, detailed paragenetic tables were drawn up for the individual Fe, Cu and Sn mineralisations, culminating in an overall paragenetic table for all the mineralisations at Pelepah Kanan (Fig. 11).

Detailed EPMA study of the nature of the K-feldspars in the cassiterite-K-feldspar quartz veins revealed that their pinkish colour is due to the alteration to iron oxide of the Fe-Mn-O material infilling the cleavages of the K-feldspar (Fig. 12).

In addition EPMA mapping of the highly pleochroic cassiterite bands revealed that the darker coloured zones are due to the presence of higher Fe content.

A study was carried out on the tailings site at the entrance to the mine with the view of determining the economic value of the mine's tailings and determining the nature of the main and other minerals present so that the milling process can be better tuned to recover the iron. Samples were also collected at different horizons. EPMA X-ray mapping show that the tailings should be reassessed for possible treatment due to their seemingly high iron content (80-90%) (Samples CN1-L1 and CN1-L3, Table 1), however, care should be taken in localities with high tin contents as well (sample CN1-L1) (Fig. 13) as this will jeopardise the grade of the iron ore.

CONCLUSIONS

The present study show that the mineralisation at the Waterfall Mine, Pelepah Kanan is essentially a replacement body within a calc-silicate sequence with an early Fe-Sn mineralisation being intruded by a later copper mineralisation and an even later cassiterite-K-feldspar-quartz vein swarm cutting the earlier two mineralisations along fissures, joints and faults.

The EPMA also revealed the presence of minerals not reported before at Pelepah Kanan namely, native Bi, tennantite and wittichenite. EPMA X-ray mapping showed that the pinkish nature of the K-feldspars associated with tin mineralisation is due to the alteration of Fe-Mn-O materials along cleavages and the dark brown coloured zoning so characteristic of the highly pleochroic cassiterites at Pelepah Kanan is essentially due to higher Fe contents within the dark bands or zones.

The geology and mineralization is fascinating at the Waterfall Mine, Pelepah Kanan and further, more detailed investigations will definitely not fail to turn up something new and exciting.

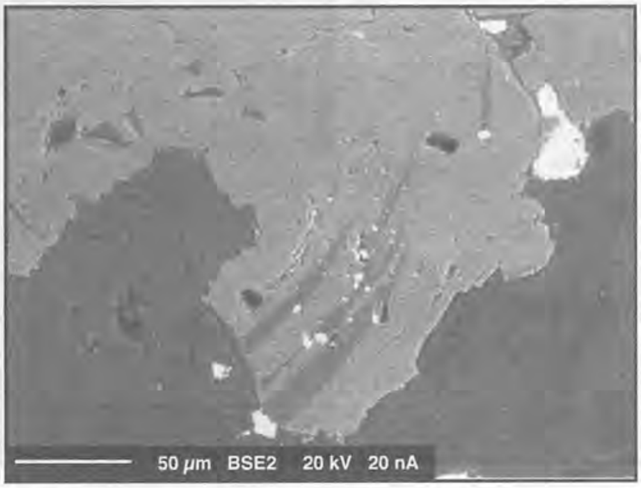

Figure 10. Gold infilling fractures between magnetite (grey) and calc-silicate hornfels (dark grey).

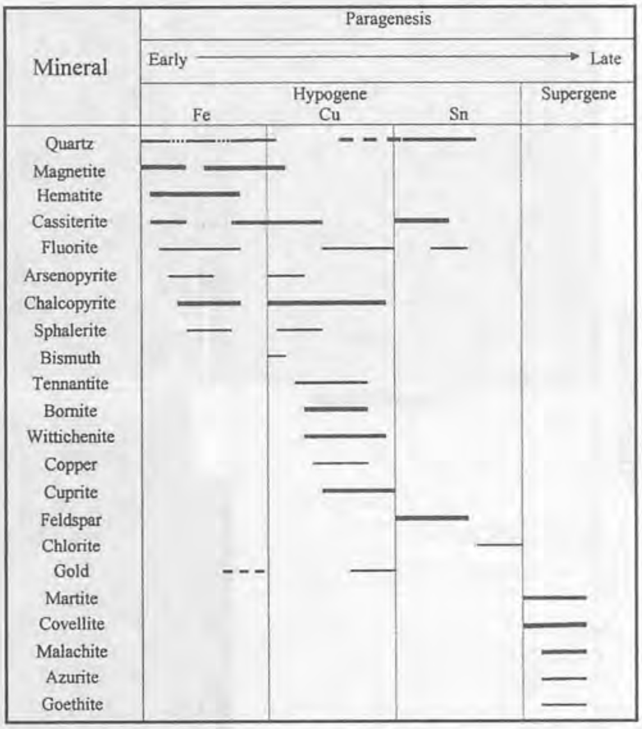

Figure 11. Overall paragenetic table for the Fe, Cu and Sn mineralisations at Pelepah Kanan.

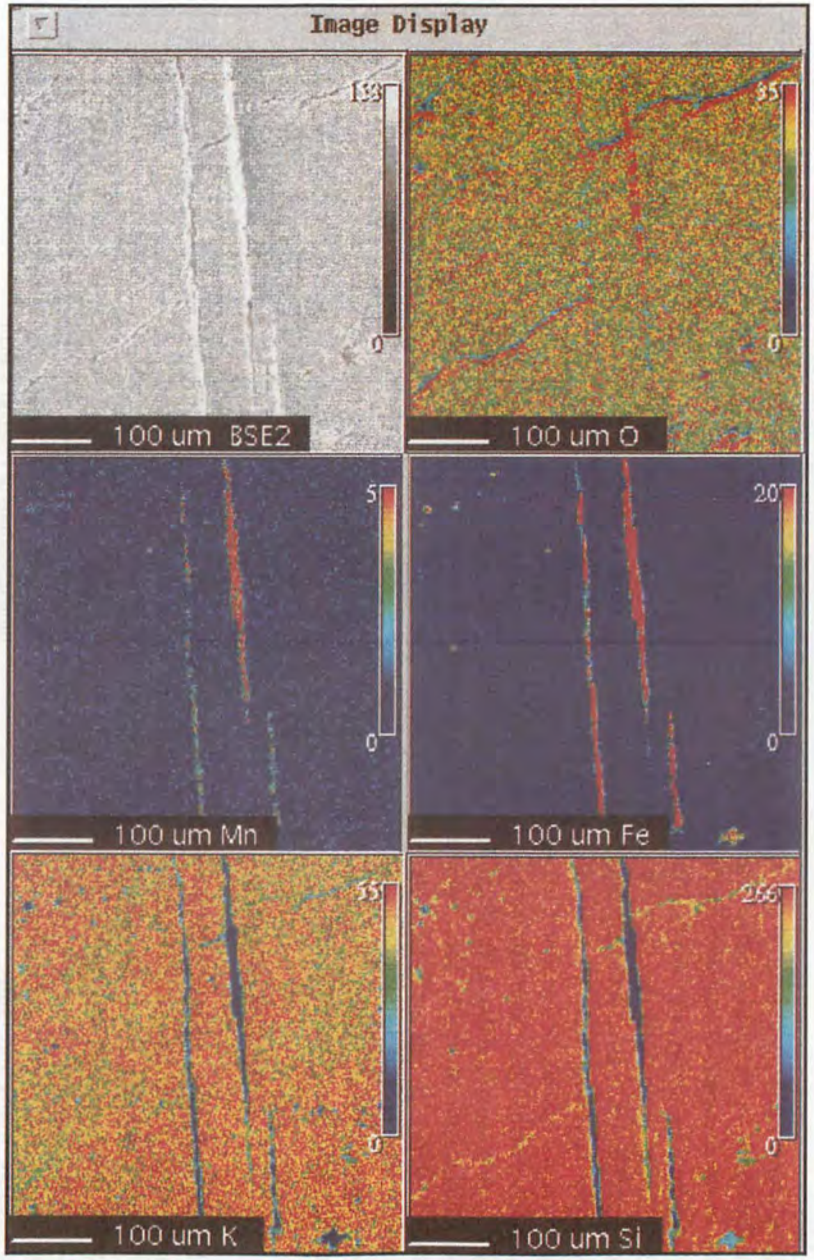

Figure 12. EPMA X-ray map showing that the pinkish tint of K-feldspars is due to the alteration of Fe-Mn-O material infilling the cleavages.

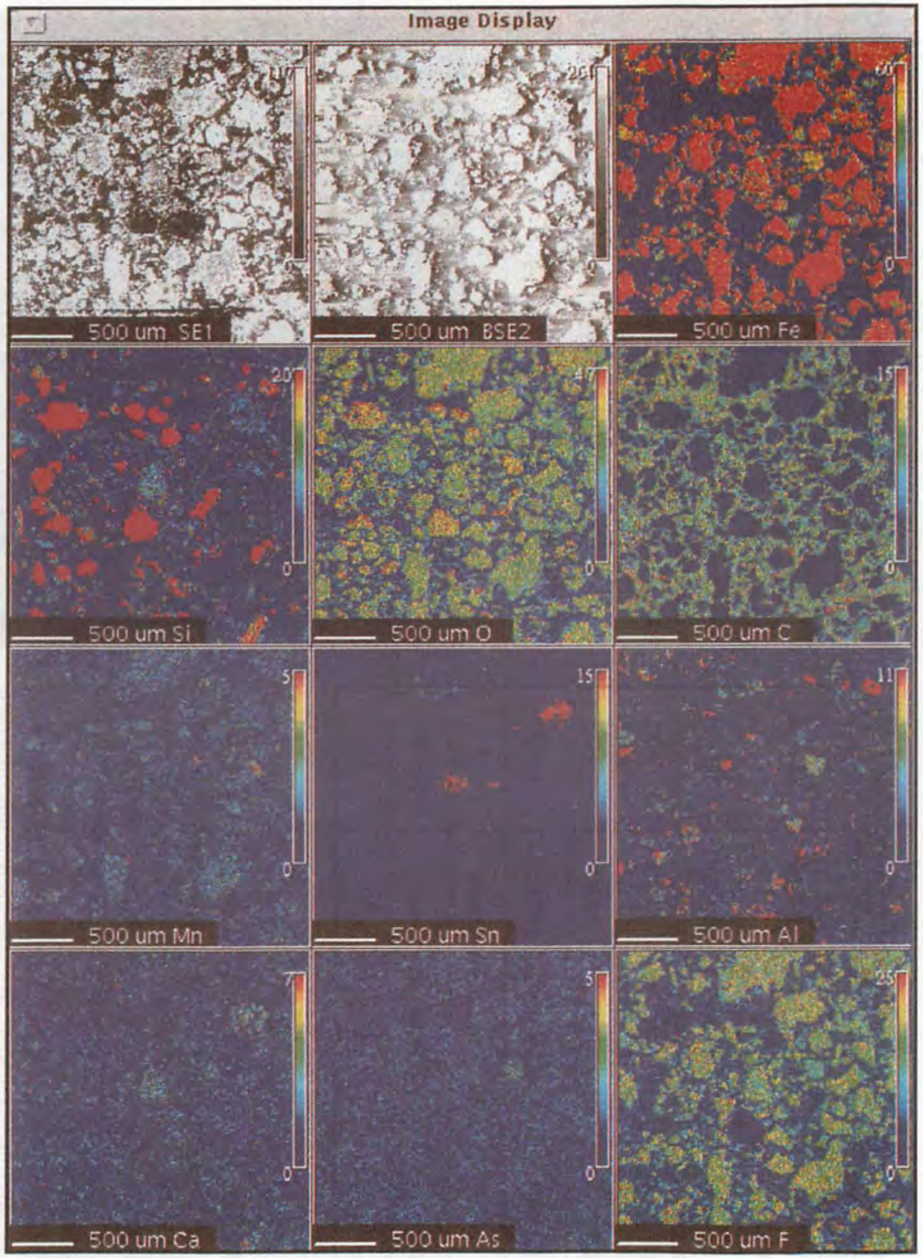

Figure 13. EPMA X-ray mapping of tailings sample (CN1-L1) showing significant amounts of magnetite (Fe, O) (81.48%) and cassiterite (Sn, O) (17.04%).

ACKNOWLEDGEMENTS

Financial assistance provided by the University of Malaya for the preparation and presentation of this paper is greatly appreciated.

REFERENCES

ABDULLAH HASBI HASSAN, MOHD ZAKI AND HUSIN, H., 1981. Mineability and beneficiation of tin – iron ores in Malaysia. *In: Proc. Seminar on Complex Tin Ores and Related Problems*, SEATRAD Centre, Ipoh, 245-271.

ADONG LAMING, 2001. *Pemineralan besi, timah dan tembaga di Lombong Air Terjun, Kota Tinggi, Johor*. Unpubl. MSc thesis, University Kebangsaan Malaysia, 216p.

BEAN, J.H., 1969. The iron ore-deposits of West Malaysia. *Econ. Bull. 2 Geol. Survey Malaysia*, 87-95.

BURTON, C.K., 1959. A note on the geology of the tin and iron-bearing deposits located near Sungai Pelepah Kanan District of KotaTinggi, Johore. *Geological Papers 3*, Geological Survey Malaysia, 17-36.

CHENG ENG CHOON, 1975. *The Geology of the Pelepah Kanan Area, Johore, with emphasis on in-situ mineralisation there*. Unpubl. BSc thesis, University of Malaya, 65p.

CHU, L.H., CHAN, F. AND SANTOKH, D.S., 1984. Primary tin mineralisation in Peninsular Malaysia: aspects of geological setting and exploration strategy. *In:* The International Symposium on Geology of Tin Deposits, Nanning City, China.

GANESAN, K., 1969. Geological note on iron-tin mineralisation in the Gunung Muntahak area, Johore. *Geol. Soc. Malaysia Newsletter 19*, 1-5.

GANESAN, K., 1976. Stanniferous axinite and garnet from a hornfelsic skarn rock from Pelepah Kanan Mines, Kota Tinggi, Peninsular Malaysia (abstract). *In:* Geology of the South China Sea area including its Continental Rim — Discussion Meeting (Abstracts of Papers), Ipoh, Perak.

GRUBB, P.L.C. AND HANNAFORD, P., 1966a. Ferromagnetism and colour zoning in some Malayan cassiterite. *Nature 209*, 677-678.

GRUBB, P.L.C. AND HANNAFORD, P., 1966b. Magnetism in cassiterite; its source and paragenetic significance as exemplified by a prominent Malayan tin deposit. *Mineralium Deposita 2*, 148-171.

HOSKING, K.F.G., 1973. Primary mineral deposits. *In:* Gobbett, D.J. and Hutchison, C.S. (Eds.), *Geology of the Malay Peninsula*. Wiley Interscience, 355-390.

KEE THUAN MOORE, 1966. *Geology of Gunung Panti area*. Unpubl. BSc (Hons) thesis, University of Malaya.

KHOO HAN PENG, 1969. *Mineralisation of Pelepah Kanan area, Kota Tinggi, Johor, West Malaysia*. Unpubl. BSc thesis (Hons) thesis, University of Malaya, 103p.

LEE HENG POH, 2002. *EPMA study on Fe-Sn-Cu mineralisation at Waterfall Mine, Pelepah Kanan, Johor*. Unpubl. BSc thesis, University of Malaya, 52p.

NOR SAAWALUDIN MOHD. NOR, 1983. *Geologi kawasan Pelepah Kanan dan pemineralan di Lombong Pelepah Kanan, Kota Tinggi, Johor*. Unpubl. BSc thesis, University of Malaya, 108p.

ROE, F.W., 1941. *Visit to Pelepah Kanan Mine*. Unpubl. Report, GS61/41, Geol. Survey Dept. Malaysia.

TEH, G.H. AND DONNY OSMOND ANAK JULIUS, 2002. EPMA study of heavy minerals in Annah Rais-Bayur area, Sarawak. *Proceedings Annual Geological Conference 2002*, Geol. Soc. Malaysia, 369-375.

WAN FUAD WAN HASSAN, HERU SIGIT PURWANTO AND ADONG LAMING, 2000. Tembaga Porfiri di Pelepah Kanan, Kota Tinggi, Johor. *Proceedings Annual Geological Conference 2000*, Geol. Soc. Malaysia, 333-337.

WILLBOURN, E.S., 1936. *Deposit of tin-ore in iron-ore at Pelepah Kanan, Kota Tinggi, Johore, prospected by Ishihara Sangyo Koshi*. Unpubl. Enclosure No. 7, GS 323/36, Geol. Survey Dept., Malaysia.

YEAP EE BENG, 1982. Reinterpretation of the Fe-Sn mineralisation at the Waterfall Mine, Pelepah Kanan, Johore (abstract). *Warta Geologi, 8(5)*, 228-229.

ZUBAIDI ABBAS, 1983. *Perubahan batuan dinding pada telerang berkasiterit, Kota Tinggi, Johor*. Tesis Sarjanamuda Sains, Universiti Kebangsaan Malaysia.

Manuscript received 29 March 2003