# Reichenbachite from Cornwall and Portugal

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## Abstract

Infrared spectroscopy is a rapid method of distinguishing between pseudomalachite and its polymorphs reichenbachite and ludjibaite. This technique, backed by X-ray diffraction has shown that a number of specimens labelled 'pseudomalachite' from Cornwall, in particular from Old Gunnislake mine, are of reichenbachite, thus identified for the first time from the British Isles. Reichenbachite has also been identified with pseudomalachite from Miguel Vacas mine, Vila Viçosa, Evora, Portugal. Identification of pseudomalachite from a number of other localities world-wide has been confirmed, and some specimens have been shown to be arsenatian.

KEYWORDS: reichenbachite, pseudomalachite, ludjibaite, infrared spectroscopy, Cornwall, Portugal.

#### Introduction

PSEUDOMALACHITE (Hausmann, 1813) is the accepted name for the copper phosphate mineral described under a variety of names, including ehlite (Breithaupt, 1832), lunnite (Bernhardi,. 1839), and prasine (Breithaupt, 1841), and assigned various compositions, but now formulated  $Cu_5(PO_4)_2(OH)_4$ . It has been reported from numerous worldwide localities. British pseudomalachite ('lunnite'), from an unspecified locality in Cornwall, was first analysed by Heddle (1855). Maskelyne and Flight (1872) gave an analysis of 'prasine' which was supplied by the dealer Richard Talling and was associated with white olivenite, and was therefore probably also Cornish, although no locality is given. Church (1873) analysed three Cornish, but not further localized specimens of 'ehlite' and concluded that they were the phosphate analogue of cornwallite and identical with the 'pseudomalachite' 'of Dana' (actually of Hausmann) and the 'ehlite' of Breithaupt. According to Rudler (1905), specimens of 'lunnite or pseudomalachite' from Botallack, Cornwall, were analysed by Professor Church, but the reference given (J. Chem. Soc.,

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1865, p. 2) is incorrect. No relevant paper by Church other than that mentioned above has been traced, and Botallack as a locality has not been mentioned in the literature again until recently (Bowell, 1992). Kingsbury (1952) specifies five localities for 'pseudomalachite' in Cornwall.

## Description

Old Gunnislake mine, Calstock, Cornwall, is one of the best known British localities for 'pseudomalachite' (Kingsbury, 1952), but in 1982 we observed that specimens from here gave infrared spectra similar to but distinctly different from that of authentic pseudomalachite. Moreover, three out of six early 19th century specimens of typical 'pseudomalachite' in the Lady Elizabeth Cornwallis collection in Maidstone Museum, labelled 'compact malachite' or 'malachite' from Cornwall, also gave the abnormal infrared pattern. In 1987 a sample of reichenbachite, the newly described polymorph of pseudomalachite (Sieber *et al.*, 1987), became available to the authors and its infrared spectrum



FIG. 1. Scanning electron photomicrograph of reichenbachite crystals from Cornwall. Off Maidstone Museum specimen 179. Lady E. Cornwallis Collection.

was found to be identical with those of the abnormal 'pseudomalachite' specimens from Old Gunnislake mine. The identification was confirmed by X-ray powder diffraction at the Natural History Museum, London, and is the first of reichenbachite from the British Isles.

Reichenbachite from Old Gunnislake mine was particularly common on Michael's shaft dump (National Grid Reference SX 430 719), formerly a well-known collecting site marked by an ivycovered chimney, but now built over. It is a supergene mineral, of late generation, typically forming dark green crusts to mammillary coatings, sometimes several mm thick, with compact, indistinctly fibrous radiating structure, and with minutely drusy outer surfaces. Scanning electron photomicrographs (Fig. 1) show the crystal terminations displayed on such drusy surfaces, and may be compared with the SEM photograph of the type material figured in Sieber et al (1987). The coatings are usually found as crack fillings and cavity linings on a matrix of milky, somewhat iron-stained, vein quartz with some decomposed feldspar; occasionally they are associated with chrysocolla, fibrous malachite or rectangular plates of metatorbernite. A fine specimen in the Natural History Museum, London (BM 1973,72, from R. W. Barstow) exhibits well-formed emerald green 0.02 mm platy crystals of reichenbachite on the dark green surface of a bluish-green translucent massive crust of reichenbachite 1-2mm thick.

Seven specimens from Old Gunnislake mine have now been confirmed as reichenbachite by infrared spectroscopy, together with the three Maidstone Museum specimens from Cornwall mentioned above. In addition, a batch of specimens said to have come from Williams' shaft dumps of the same mine (SX 430 7185) in 1986 also proved to be reichenbachite, but another specimen from this dump was of normal pseudomalachite, as was a specimen consisting of a green crust underlying arsenatian libethenite crystals from East Gunnislake mine (SX 433 718). Normal pseudomalachite was also confirmed on three specimens labelled 'Gunnislake mine' or 'Old Gunnislake mine', so it appears that both polymorphs occur at Gunnislake, reichenbachite perhaps being more common, particularly on material known to have come from Michael's shaft (e.g. that collected by the authors). Unfortunately, the two polymorphs appear to be indistinguishable except by X-ray diffraction or infrared spectroscopy.

Reichenbachite has hitherto been reported only from the type locality, Reichenbach, Germany (Sieber et al., 1987) and from Lubietova (= Libethen), Slovakia (Hyrsl, 1991). The discovery of the Gunnislake occurrence prompted us to study 'pseudomalachite' samples from a wide range of localities, though concentrating particularly on SW England, using infrared spectroscopy as a rapid and easy method of distinguishing between the polymorphs. This led to the identification of reichenbachite from Miguel Vacas mine, Vila Viçosa, Evora, Portugal. This mine is a known locality for pseudomalachite (Magalhães et al., 1988), but specimens collected by one of us (RSWB) from the dumps in 1969 were shown to carry reichenbachite. This forms dark green, matt-surfaced mammillary coatings and small spherules, closely associated with libethenite crystals and usually underlying the latter. One specimen displays small globules of reichenbachite dispersed on libethenite crystals and on a somewhat darker green coating of compact fibrous radiating pseudomalachite, on which the libethenite is sprinkled. The matrix of these specimens is of white vein quartz and 'limonite' in a grey slate. The localities at which normal pseudomalachite has been confirmed by our survey are listed in Table 1; note that some are arsenatian, easily distinguished by infrared spectroscopy by the enhanced absorption in the 840 cm<sup>-1</sup> region (cf. pyromorphite group; see Braithwaite, 1990).

#### Polymorphs

Studies of synthetic phases formed by hydrothermal techniques in the  $CuO-P_2O_5-H_2O$ system revealed the formation of three polymorphs of  $Cu_5(PO_4)_2(OH)_4$ , which were labelled PM (pseudomalachite), PPM and QPM TABLE 1. List of localities at which pseudomalachite has been confirmed by infrared spectroscopy (this work)

LocalityRemarksSpecimens examinedMuseum specimen numbers(*)England: Cornwall: Whall Carpenter, Gwinear Penberthy Croft mine, St Hilary South Whael Frances, Illogan United mines, St Day Whael Unity, St Day Whael Phoenix, Linkinhorne Gunnislake mine, CalstockArsenatian, underlying malachite Infecting in the themic crystals and malachite Infecting in the themic crystalsInfecting infecting i				
England: Cornwall: Wheal Carpenter, Gwinear Penkerty, Corinica, St Hiary South Wheal Frances, Illogan Tolaram enic, Camborne Myheal Unity, St Day Wheal Phoenix, Linkinhorne Gunnislake mine, CalstockArsenatian, with libethenite crystals and malachite Bright-green minute spherules% Illower, with libethenite crystalsInterpret Nev 1985,3530.Wheal Unity, St Day Wheal Phoenix, Linkinhorne Gunnislake mine, CalstockOne specimen was arsenatian Specimen BM 61333 <sup>(6)</sup> is arsenatian One specimen was from Williams Spath dumpImel. BM 1929,216. BM 4372,44672,44673. Specimen BM 61333 <sup>(6)</sup> is arsenatian One specimen was from Williams Spath dumpEast Gunnislake mine, CalstockUnderlying libethenite crystalsImel. BM 1926,134 & 1985,12199; BM 61333.Oid Gunnislake mine, CalstockUnderlying libethenite crystalsImel. BM 1968,134 & 1988,135.East Gunnislake mine, CalstockArsenatian Arsenatian, with bayldonite ArsenatianImel. BM 1968,134 & 1968,135.England: Cumbria: Portugal: Evora: Miguel Vacas mine, VirnebergArsenatian, with bayldonite Arsenatian, sheafy pseudomorphs?Imel. BM 1968,136.Stowakia: Lubietova (= Libethen)Arsenatian, sheafy pseudomorphs?Imel. BM 1968,316.Zarre: Kambiove, Katanga Wissa mine, Noth Arlington Vichanga mine, Noth Arlington Vichanga mine, Noth Arlington Vichanga mine, Noth ArlingtonDihydrite', thin green crustUSAki: Cold Sobyler mine, Noth Vichanga mine, Noth Chanshik, between Chingola Chambishi, between Chingola Chambishi, between Chingola Chambishi, between Chingola Chambishi, between Chingola Chambishi, between Chingola Chambishi, between Chingola Chambis	Locality	Remarks	Specimens examined	Museum specimen numbers <sup>(a)</sup>
Wheal Competer, Gorinear   Arsenatian, underlying malachite   1     Penberthy Croft mine, St Hilay   Bright-green minute spherules <sup>60</sup> 1     South Wheal Frances, Illogan   With libethenite crystals and malachite   1     Tokarne mine, Canborne   Arsenatian, with libethenite crystals and malachite   1     Wheal Unity, St Day   0   BM 31243.     Wheal Phoenix, Linkinhorne   One specimen was arsenatian   3     Old Gunnislake mine, Calstock   Specimen BM 61333 <sup>60</sup> is arsenatian.   2     Old Gunnislake mine, Calstock   One specimen was from Williams   2     Specimen BM 61333 <sup>60</sup> is arsenatian   1   1985,12199; BM 61333.     Old Gunnislake mine, Calstock   Underlying libethenite crystals   1     Eagland: Devon:   Bampfylde mine, North Molton   3   incl. BM 1968,134 & 1968,134 & 1968,135.     England: Cumbria:   Portugal: Evera:   Arsenatian   1     Auchencain baryte mine, Retrick   Translucent drusy crusts on quartz <sup>60</sup> 2     Portugal: Evera:   Mizeu Yen Mine, Charlock Fells   Arsenatian, sheafy pseudomorphs?   1     Slowakia:   1   M/C Mus. N3807.   Slowakia:     Lubetova (= Libethen)   1	England: Cornwall:			
Wheat Carponier, Owneal   Arsenatian, ducerying inducting   1     South Wheat Frances, Illogan   With hibthemite crystals and malachie   1     South Wheat Prances, Illogan   With hibthemite crystals and malachie   1     Tolearne mine, Camborne   Arsenatian, with libethemite crystals   1     Wheat Unity, St Day   0   BM 31243.     Wheat Phoenix, Linkinhorne   3   BM 44571, 44572, 44673.     Gunnislake mine, Calstock   One specimen Was arsenatian   2     Old Gunnislake mine, Calstock   One specimen Was from Williams   2     East Gunnislake mine, Calstock   Underlying inbethenite crystals   1     East Gunnislake mine, Calstock   Underlying inbethenite crystals   1     East Gunnislake mine, Calstock   Underlying inbethenite crystals   1     East Gunnislake mine, Calstock   Arsenatian   1     Specimen BM (5133) <sup>CD</sup> is arsenatian   3   incl. BM 1968,134 & 1968,135.     England: Cumbria:   Arsenatian   1   1     Portugal: Evora:   Translucent drusy crusts on quartz <sup>GD</sup> 2     Portugal: Evora:   Translucent drusy crusts on quartz <sup>GD</sup> 1   M/C Mus. N3807.     Slowahize: <t< td=""><td>Wheel Comenter Chuineer</td><td>A reapation underlying malachite</td><td>1</td><td></td></t<>	Wheel Comenter Chuineer	A reapation underlying malachite	1	
Performative Continuities of Frances, Illogan With Bothemite crystals and malachite   1     Tokarne mine, Camborne   Arsenatian, with libethemite crystals and malachite     United mines, St Day   1     Wheal Unity, St Day   0     Wheal Unity, St Day   0     Wheal Phoenix, Linkinhorne   0     Gunnislake mine, Calstock   5     Specimen BM 61333 <sup>(6)</sup> is arsenatian   3     Bampfylde mine, Calstock   5     Specimen Was from Williams   2     shaft dump   2     Potts Gill mine, Caldbock Fells   Arsenatian     England: Devor:   3     Bampfylde mine, North Molton   3     Scotland: Kirkcudbrightshire:   Arsenatian     Auchencair hoarty mine, Retrick   Translucent drusy crusts on quartz <sup>(0)</sup> Stortgal: Evera:   Translucent drusy crusts on quartz <sup>(0)</sup> Miguel Vacas mine, Vila Viçosa   3     Germany: Rheitland-Pfalz:   Fil     Fil   Arsenatian, sheafy pseudomorphs?   1     M/C Mus. N3816.   2     Zarie:   Kambove, Katanga   2     M'seas mine, Chagola & Kitwe   1     Bwandski:   1	Parkarthy Craft mine St Hilem	Bright graam minute anhamiles <sup>(b)</sup>	1	
South Wreal Prances, llogan   With Incinentic Prystals and matachine   1     Tolcarne mine, Camborne   Arsenatian, with libethenite crystals   1     Wheal Unity, St Day   1   Nev 1985,3530.     Wheal Dhoenix, Linkinborne   One specimen was arsenatian   3   1     Gunnislake mine, Calstock   One specimen was from Williams   2     Sold Gunnislake mine, Calstock   Underlying libethenite crystals   1     East Gunnislake mine, Calstock   Underlying libethenite crystals   1     East Gunnislake mine, Calstock   Underlying libethenite crystals   1     England: Cumbria:   Portor:   3   incl. BM 1968,134 & 1968,134     Potts Gill mine, Caldbeck Fells   Arsenatian, with bayldonite   2     Scotland: Kirkcudbrightshire:   Arsenatian, with bayldonite   2     Auchencairn baryte mine, Retrick   Translucent drusy crusts on quartz <sup>60</sup> 2     Briguel Vacas mine, Vila Viçosa   3   3   incl. BM 1968,316.     Zaire:   Kambove, Katanga   2   incl. BM 1968,316.   3     Zaire:   Kambove, Katanga   2   incl. BM 1968,316.   3     Zaire:   Kambove, Katanga   1	Penderiny Croit mine, St Hilary	Wish libeth minute spherules	1	
Tolcarne mine, Camborne   Arsenatian, with ibethenite crystals   1     Wheal Unity, St Day   0ne specimen was arsenatian   1     Wheal Phoenix, Linkinhorne   One specimen was arsenatian   3     Gurnislake mine, Calstock   Specimen BM 61333 <sup>(6)</sup> is arsenatian   2     Old Gunnislake mine, Calstock   Specimen BM 61333 <sup>(6)</sup> is arsenatian   1     East Gunnislake mine, Calstock   Underlying libethenite crystals   1     England: Devon:   3   incl. BM 1968,134 & 1968,135.     England: Cumbria:   Portugal: Cumbria:   1     Potts Gill mine, Calstock   Arsenatian, with bayldonite   2     Scolland: KirkcuBrightshire:   Arsenatian, with bayldonite   2     Portugal: Evora:   Translucent drusy crusts on quartz <sup>(6)</sup> 2     Miguel Vacas mine, Vila Viçosa   3   3 <i>Germany: Rheinland-Ffalz:</i> Arsenatian, sheafy pseudomorphs?   1   BM 42475,     Ehl   Arsenatian, sheafy pseudomorphs?   1   M/C Mus. N3807.     Slowakia:   Lubietova (= Libethen)   1   M/C Mus. N3816.     Zarie:   Xambove, Katanga   2   incl. BM 1968,316.     Wissa mine, Naine, Otingola & Kitwe	South wheat Frances, Illogan	with indefinentie crystals and malachit	e I	
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Wheal Unity, St Day   One specimen was arsenatian   1   BM 31243,     West Wheal Phoenix, Linkinhorne   One specimen was arsenatian   3   incl. BM 1929,216.     Strunislake mine, Calstock   Specimen BM 61333 <sup>(5)</sup> is arsenatian   2   MI 1985,12199; BM 61333.     Old Gunnislake mine, Calstock   Underlying libethenite crystals   1   BM 1929,216.     East Gunnislake mine, Calstock   Underlying libethenite crystals   1   MI 1985,12199; BM 61333.     England: Devon:   Bampfylde mine, North Molton   3   incl. BM 1968,134 & 1968,135.     England: Cumbria:   Arsenatian   1   1968,135.     England: Cumbria:   Arsenatian   1   1968,135.     England: Lableck Fells   Arsenatian   1     Scouland: Kirkcubrightshire:   Arsenatian   3   incl. BM 1968,134 & 1968,135.     Germany: Rheinland-Ffalz:   Translucent drusy crusts on quartz <sup>(6)</sup> 2   incl. M/C Mus. N3807.     Slowakia:   Lubietova (= Libethen)   1   M/C Mus. N3816.   2     Zarrei:   Katanga   2   incl. BM 1968,316.   2     Zarrei:   Sovakia:   1   BM 1929,1633.   1	United mines, St Day		1	Nev 1985,3530.
Wheal Phoenix, Linkinhorne   One specimen was arsenatian   3   incl. BM 1929,216.     West Wheal Phoenix, Linkinhorne   Specimen BM 6133 <sup>(6)</sup> is arsenatian   2   BM 44671, 44672, 44673.     Gunnislake mine, Calstock   Specimen BM 6133 <sup>(6)</sup> is arsenatian   2   MI 1985,12199; BM 61333.     Cold Gunnislake mine, Calstock   Underlying libethenite crystals   1   1     England: Devon:   Bampfylde mine, North Molton   3   incl. BM 1968,134 & 1968,135.     England: Devon:   Bampfylde mine, Caldbeck Fells   Arsenatian   1     Low Pike trial, Caldbeck Fells   Arsenatian, with bayldonite   2     Scotland: Kirkcudbrightshire:   Acuchencair baryte mine, Retrick   Translucent drusy crusts on quartz <sup>(6)</sup> 2     Portugal: Evora:   Mice Mine, Vireberg   1   M/C Mus. N3807.     Slovakia:   Lubertora (= Libethen)   1   M/C Mus. N3807.     Slovakia:   Lubietora (= Libethen)   1   M/C Mus. N3816.     Zanita:   Yorkaga mine, Chingola & Kitwe   1   BM 1929,1633.     N'changa mine, Chingola & Kitwe   1   BM 1929,1633.   M/C Univ. Geol. Dept. 2847.     Slovakia:   USA: New Jersey:   'Dihydrite', thin green crust	Wheal Unity, St Day		1	BM 31243.
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Gunnislake mine, Calstock   Specimen BM 6133 <sup>6</sup> ) is arsenatian   2   MI 1985,12199; BM 61333.     Old Gunnislake mine, Calstock   One specimen was from Williams   2     East Gunnislake mine, Calstock   Underlying libethenite crystals   1     England: Devon:   3   incl. BM 1968,134 & 1968,135.     England: Cumbria:   7   1     Potts Gill mine, Caldbeck Fells   Arsenatian   1     Low Pike trial, Caldbeck Fells   Arsenatian   2     Short Grain, Caldbeck Fells   Arsenatian   3     Scotland: Kirkcudbrightshire:   Arsenatian, with bayldonite   2     Portugal: Evora:   Translucent drusy crusts on quartz <sup>(d)</sup> 2     Portugal: Evora:   1   M/C Mus. N3799.     Stozkia:   1   M/C Mus. N3807.     Slovakia:   2   incl. M/C Mus. N3807.     Slovakia:   2   incl. BM 1968,316.     Zaire:   Kambove, Katanga   2     N'changa mine, Chingola   Chingola & Kitwe   1     N'changa mine, Chingola   'Dihydrite', thin green crust   1     M/C Univ. Geol. Dept. 2847.   1   M/C Mus. N3806.     Zaire:	West Wheal Phoenix, Linkinhorne		3	BM 44671, 44672, 44673.
Old Gunnislake mine, Calstock   One specimen was from Williams 2 shaft dump     East Gunnislake mine, Calstock   Underlying libethenite crystals     Eagland: Devon:   3     Bampfylde mine, North Molton   3     England: Cumbria:   3     Potts Gill mine, Caldbeck Fells   Arsenatian     Low Pike trial, Caldbeck Fells   Arsenatian, with bayldonite     Scotland: Kirkcudbrightshire:   Arsenatian     Auchencairn baryte mine, Retrick   Translucent drusy crusts on quartz <sup>(d)</sup> Scotland: Kirkcudbrightshire:   Arsenatian, sheafy pseudomorphs?     Miguel Vacas mine, Vila Viçosa   3     Germany: Rheinland-Pfalz:   Arsenatian, sheafy pseudomorphs?     Ehl   Arsenatian, sheafy pseudomorphs?     Slovekia:   1     Lubietova (= Libethen)   1     M'resa mine, Chingola   2     N'changa mine, Chingola   Kitwe     Sman M' kubwa, Ndola   1     BM 1929,1633.   1     USA: New Jersey:   'Dihydrite', thin green crust   1     M/C Mus. N3806.   1     BM 1929,1633.   M/C Mus. N3806.     Lubietova (= Libethen)   'Dihydrite', with massive libethenite	Gunnislake mine, Calstock	Specimen BM 61333 <sup>(c)</sup> is arsenatian	2	MI 1985,12199; BM 61333.
East Gunnislake mine, Calstock   Underlying libethenite crystals   1     England: Devon: Bampfylde mine, North Molton   3   incl. BM 1968,134 & 1968,134 & 1968,135.     England: Cumbria: Potts Gill mine, Caldbeck Fells   Arsenatian   1     Low Pike trial, Caldbeck Fells   Arsenatian, with bayldonite   2     Short Grain, Caldbeck Fells   Arsenatian   2     Auchencairn baryte mine, Retrick   Translucent drusy crusts on quartz <sup>(4)</sup> 2     Portugal: Evora: Miguel Vacas mine, Vila Viçosa   3   3     Germany: Rheinland-Pfalz: Ehl   Arsenatian, sheafy pseudomorphs?   1   BM 42476.     Slovakia: Lubietova (= Libethen)   1   M/C Mus. N3807.   3     Zaire: Kambove, Katanga   2   incl. BM 1968,316.   2     Zaire: Chambishi, between Chingola & Kitwe   1   BM 1929,1633.   BM 1929,1633.     USA: New Jersey: Old Schyler mine, North Arlington   'Dihydrite', thin green crust   1   M/C Mus. N3806.     Old Schyler mine, NS.W.   1   M/C Mus. N3806.   3	Old Gunnislake mine, Calstock	One specimen was from Williams shaft dump	2	
England: Devon: Bampfylde mine, North Molton3incl. BM 1968,134 & 1968,135.England: Cumbria: Potts Gill mine, Caldbeck FellsArsenatian Arsenatian, with bayldonite1Low Pike trial, Caldbeck FellsArsenatian, with bayldonite2Scotland: Kirkcudbrightshire: Auchencairn baryte mine, RetrickTranslucent drusy crusts on quartz(6)2Portugal: Evora: Miguel Vacas mine, Vila Viçosa33Germany: Rheinland-Pfalz: EhlArsenatian, sheafy pseudomorphs?1BM 42476. Slovakia: Lubietova (= Libethen)1M/C Mus. N3799.Slovakia: Kambove, Katanga2incl. BM 1968,316.Zambia: N'changa mine, Chingola Chambishi, between Chingola & Kitwe2incl. BM 1968,316.VSA: New Jersey: Old Schyler mine, North Arlington 'Dihydrite', thin green crust1M/C Mus. N3806.Old Schyler mine, NS.W.1M/C Mus. N3806.	East Gunnislake mine, Calstock	Underlying libethenite crystals	1	
Bampfylde mine, North Molton   3   incl. BM 1968,134 & 1968,135.     England: Cumbria:   1     Potts Gill mine, Caldbeck Fells   Arsenatian     Low Pike trial, Caldbeck Fells   Arsenatian, with bayldonite     Short Grain, Caldbeck Fells   Arsenatian     Short Grain, Caldbeck Fells   Arsenatian     Scotland: Kirkcudbrightshire:   Arsenatian     Auchencairn baryte mine, Retrick   Translucent drusy crusts on quartz <sup>(6)</sup> 2     Portugal: Evora:   Miguel Vacosa   3     Germany: Rheinland-Pfalz:   Ehl   Arsenatian, sheafy pseudomorphs?   1     BM 42476.   1   M/C Mus. N3799.     St Josephsberg mine, Virneberg   1   M/C Mus. N3807.     Slovakia:   1   M/C Mus. N3816.     Lubietova (= Libethen)   1   M/C Mus. N3816.     Zaire:   1   M/C Mus. N3816.     Zambia:   1   BM 1929,1633.     Wickanga mine, Chingola   Kitwe   1     Schuber, North Arlington   'Dihydrite', thin green crust   1     Wick Naw Jersey:   'Dihydrite', thin green crust   1   M/C Mus. N3806.     Old Schyler mine, North Arlington </td <td>England: Devon:</td> <td></td> <td></td> <td></td>	England: Devon:			
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Potts Gill mine, Caldbeck Fells   Arsenatian   1     Low Pike trial, Caldbeck Fells   Arsenatian, with bayldonite   2     Short Grain, Caldbeck Fells   Arsenatian   3     Scotland: Kirkcudbrightshire:   Auchencairn baryte mine, Retrick   Translucent drusy crusts on quartz <sup>(d)</sup> 2     Portugal: Evora:   Miguel Vacas mine, Vila Viçosa   3   3     Germany: Rheinland-Pfalz:   Ehl   Arsenatian, sheafy pseudomorphs?   1   BM 42476.     Ehl   Arsenatian, sheafy pseudomorphs?   1   BM 42476.   1   M/C Mus. N3799.     St Josephsberg mine, Virneberg   1   M/C Mus. N3807.   1   M/C Mus. N3807.     Slovakia:   1   Ubietova (= Libethen)   1   M/C Mus. N3816.     Zaire:   Kambove, Katanga   2   incl. BM 1968,316.     Zambia:   N'changa mine, Chingola   4   1     N'changa mine, Koingola & Kitwe   1   BM 1929,1633.   1     Bwana M'kubwa, Ndola   1   BM 1929,1633.   1     Old Schyler mine, North Arlington   'Dihydrite', thin green crust   1   M/C Mus. N3806.     Australia:   Tambillos   'Tagilite',	England: Cumbria:			
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Scotland: Kirkcudbrightshire:   Translucent drusy crusts on quartz <sup>(d)</sup> 2     Portugal: Evora:   3     Miguel Vacas mine, Vila Viçosa   3     Germany: Rheinland-Pfalz:   1     Ehl   Arsenatian, sheafy pseudomorphs?   1     BM 42476.   1     St Josephsberg mine, Virneberg   1     St Josephsberg mine, Virneberg   1     St Josephsberg mine, Virneberg   1     M/C Mus. N3807.   1     Stovakia:   1     Lubietova (= Libethen)   1     M'sesa mine, Katanga   2     M'sesa mine, Chingola   Kitwe     Chambishi, between Chingola & Kitwe   1     Bwana M'kubwa, Ndola   1     BW 1929,1633.   USA: New Jersey:     Old Schyler mine, North Arlington   'Dihydrite', thin green crust   1     M/C Mus. N3806.   1     Australia:   1   M/C Mus. N3806.     Australia:   1   1	Short Grain, Caldbeck Fells	Arsenatian	3	
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Chambishi, between Chingola & Kitwe   1     Bwana M'kubwa, Ndola   1     USA: New Jersey:   1     Old Schyler mine, North Arlington   'Dihydrite', thin green crust   1 <i>Chile(?):</i> 'Tagilite', with massive libethenite   1 <i>Australia:</i> Tottenham, N.S.W.   1	N'changa mine, Chingola		4	
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Old Schyler mine, North Arlington   'Dihydrite', thin green crust   1   M/C Univ. Geol. Dept. 2847.     Chile(?):   Tagilite', with massive libethenite   1   M/C Mus. N3806.     Australia:   Tottenham, N.S.W.   1	USA: New Jersey:			
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Tottenham, N.S.W. 1	Australia:			
	Tottenham, N.S.W.		1	

(a) M/C = Manchester. BM, Nev and MI = Natural History Museum, London. All other specimens from the authors' collections, or submitted to the authors by various collectors.

(b) Infrared result inconclusive; XRD indicates pseudomalachite with broadened bands (J. G. Francis, pers. comm.). (c) This is the 'erinite' specimen identified as pseudomalachite by Berry (1951).

(d) Confirmed by XRD on one specimen: Livingstone (1993).



FIG. 2. Fourier Transform infrared spectra of pseudomalachite, reichenbachite and ludjibaite, measured in nujol mulls. No absorption between 3100 and 1200 cm<sup>-1</sup>. PM = pseudomalachite, N'Changa mine, Zambia; R = reichenbachite, Old Gunnislake mine, Cornwall; L = ludjibaite, Lubietova, Slovakia.

(Shoemaker and Kostiner, 1981). Their crystal structures were determined, indicating space groups  $P2_1/c$ ,  $P2_1/a$  and P1 respectively (Shoemaker *et al.*, 1977; Anderson *et al.*, 1977; Shoemaker *et al.*, 1981). Subsequently PPM was identified in nature as reichenbachite (Sieber *et al.*, 1987), and QPM was found at Ludjiba, Zaire, and described as ludjibaite (Piret and Deliens, 1988). More recent work suggests that other polymorphs might exist in nature and, indeed, the existence of a fourth, triclinic polymorph, 'XPM', has been predicted by Shoemaker and Kostiner (1981).

## Infrared spectroscopy

The infrared spectra of a considerable number of samples (Table 1) were measured mostly in nujol mulls between KBr plates, over the 4000-400

 $cm^{-1}$  range, using a variety of spectrometers of both grating and Fourier Transform types.

Examples of the spectra obtained of reichenbachite, pseudomalachite and ludjibaite are shown in Fig. 2, and wavenumbers and assignments of absorption maxima are listed in Table 2. Although intergrowths of these species are common, and successive layers of nodules may be composed of different polymorphs, the spectra tend to show one or other of the species rather than mixtures, probably because of careful sampling under the microscope.

# Conclusion

Infrared spectroscopy is a rapid method of distinguishing between the polymorphs pseudomalachite, reichenbachite and ludjibaite. Most 'pseudomalachite' specimens studied from Old

PM	R		L		Assignments
			3625	vw )	
3436 fs	3409	S	3419	s	
3387 fs			3413	s )	O–H stretch
	(~3370)		(~3370)		
~3180 vvw,br	3180	vw,br	3180	vw,br	
1098 vs	1098	VS	1107	s)	$v_3$ of PO <sub>4</sub>
(1020) vs	1042	vs	1040	vs }	possibly with
<b>999 vs</b>	992	vs	997	vs )	CuO-H
953 s	(~955)		970	S	$PO_4 v_1 \text{ or } v_3^1$
889 m	(~920)	m	(~925)	}	
	. ,		(~890)	vw	CuO-H deformation <sup>2</sup>
812 fs	839	m	827	m (	
756 fs	770	m	769	fs )	
	(~	620)	627	m)	CuO-H deformation
610 s	606	S	601	s }	or PO <sub>4</sub> $v_4$ ? <sup>3</sup>
550 m,sp	546	m	546	m )	
530 m			530	fw }	$PO_4 v_4$
510 fw	505	m	504	m )	
480 fw	475		474	fw )	
446 m	455	fw	459	fw }	$PO_4 v_2$
417 m	410	fw	419	fw )	_
360 m	390	w,br	n.d.	1	
338 m	330	w	n.d.	Į	Cu–O stretch
285 w	258	fw	n.d.	}	
250 w	(250)		n.d.	]	

TABLE 2. Wavenumbers  $(cm^{-1})$  and probable assignments of infrared absorption maxima of pseudomalachite, reichenbachite and ludjibaite

br = broad, f = fairly, m = medium. n.d. = not determined, s = strong, sp = sharp, v = very, w = weak. Values in brackets are for shoulders:

PM = pseudomalachite, N'Changa mine, Zambia; R = reichenbachite, Old Gunnislake mine, Cornwall; L = ludjibaite, Lubietova, Slovakia.

Notes (Reference: Braithwaite, 1983)

- 1 Compare band at  $950 \text{ cm}^{-1}$  in libethenite, unaffected by deuteration. 2 Compare band at  $810 \text{ cm}^{-1}$  in libethenite, shifted by deuteration.
- 3 Similar in libethenite, but not in the arsenate olivenite.

Gunnislake mine, Cornwall, consist of the  $P1_1/a$ polymorph reichenbachite, identified for the first time from the British Isles. Most of the 'pseudomalachites' studied from other localities consist of the normal  $P2_1/c$  polymorph, and some are arsenatian. Specimens from Miguel Vacas mine, Vila Viçosa, Evora, Portugal have proved to contain both reichenbachite and pseudomalachite.

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