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Metalliferous Mine Waste in West Cornwall: The Implications for Coastal Management

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Abstract: Metalliferous mining has taken place in Cornwall since the Bronze Age. Copper production in southwest England peaked at 15,255 tonnes of metal in 1860, while c. 12,794 tonnes of tin metal represented its peak production in 1870. Technologies of varied efficiency were employed in the mining industry, which produced large quantities of unwanted material. Waste was frequently disposed of by flushing sediments into local water courses. Much of this material was subsequently transported to the coastal zone. Coastal and river floodplain stratigraphies indicate the presence of mine waste deposits. These are visually distinctive, consisting of finely laminated minerogenic-dominated strata which frequently exhibit a red-brown or grey-green coloration. The structure and texture of these materials corresponds closely with documentary descriptions of mine 'tailings' or 'slimes'. Geochemical analysis of sedimentary cores from selected sites shows that coastal sediment sequences display concentrations of heavy metals in excess of that which may be expected from normal precipitation and weathering. It is concluded that any future large scale disturbance of these deposits may have a significant environmental impact due to heavy metal contamination of sediments, water and biota. A co-ordinated coastal management strategy may help minimise degradation of the coastal resource.

Introduction

Metalliferous minerals have been extracted in parts of west Cornwall since the Bronze Age. Archaeological evidence shows that tin and copper ores were first used to produce weapons and utensils (Dines, 1956). In 1663 the port town of Penzance was appointed a mining town under Royal Charter, becoming a stannary centre in the nineteenth century. The requisites and produce of local mining passed through Penzance until well into the twentieth century.

The main ore minerals found in Cornwall are casserite (SnO_2), wolframite ($[FeMn]WO_4$), arsenopyrite ($FeAsS$), chalcopyrite ($CuFeS_2$), sphalerite (ZnS) and galena (PbS). Early excavations were in casserite-bearing alluvial sands and gravels. Casserite constitutes the most important ore of tin. Also called 'stream-tin', it is known to have occurred in gravel resting immediately on bedrock and beneath alluvial silt in west Cornwall (Healy, 1993). Where conditions were favourable, it is known that alluvial deposits were repeatedly worked for tin extraction. Marine alluvial tin deposits occur in Mount's Bay and St Ives Bay (Ong, 1966), probably transported by streams flowing through the mining districts. Total production and intensity of tin workings in alluvial deposits is unknown. Copper was obtained from lodes exposed in cliffs. Later, ores of both metals were mined from shallow pits and cliff adits (Ong, 1966). The use of gunpowder and steam engines caused rapid expansion of the mining industry in the 17th and 18th centuries (Hamilton-Jenkin, 1961-1965).

Figure 1 illustrates the production of copper and tin metal in Cornwall and Devon in the period 1200 to 1950 A.D. Copper production peaked at *c.* 15,255 tonnes of metal per annum (tpa) in 1860 but was reduced to almost nil in 1900. Tin production peaked in 1870 (*c.* 12,794 tpa), falling to *c.* 4,000 tpa in 1900 and a few hundred tonnes by 1930. Additionally, a variety of other minerals (including lead and zinc) were brought to the surface as waste. While the graph represents a generalised picture based on documentary sources, it is a useful guide to interpreting the relationship between sedimentation and mining activity through time. It is, however, important to recognise that individual mines may not have conformed precisely to general production patterns.

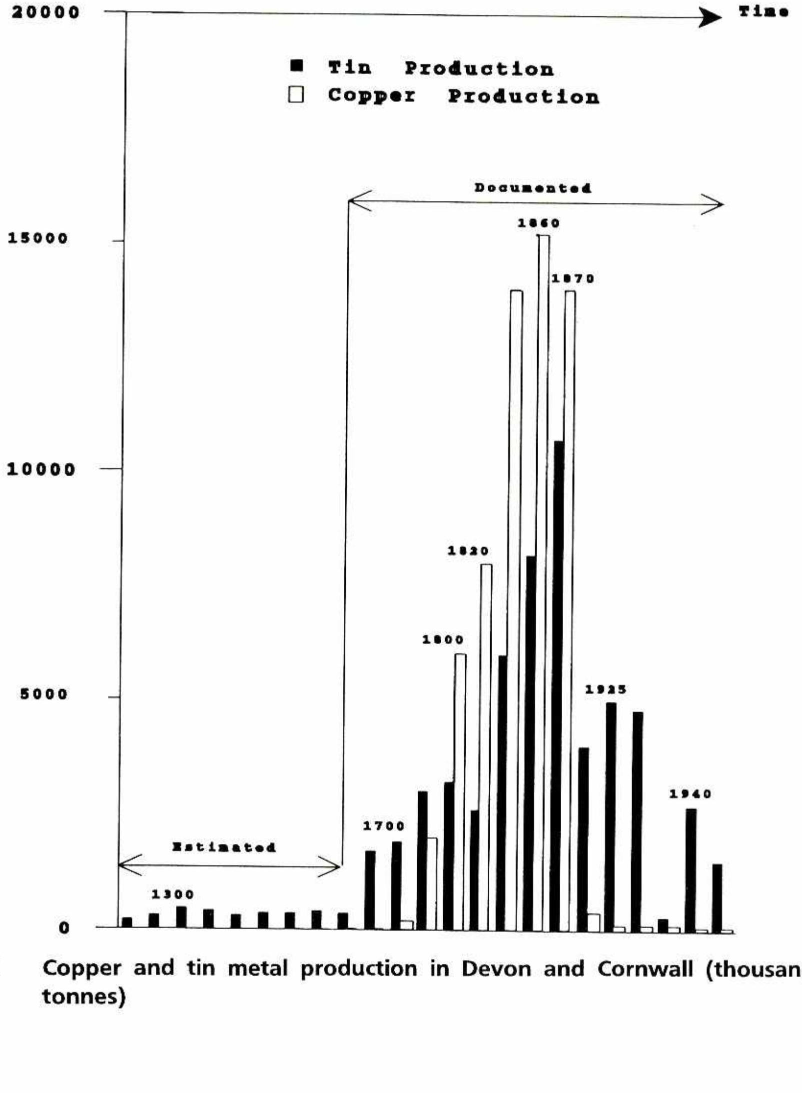

Figure 1 Copper and tin metal production in Devon and Cornwall (thousands of tonnes)

Mine waste materials

In tin and copper mining areas of Cornwall, ores rarely contained mineral grades in excess of 10% (Goode & Taylor, 1988). For this reason mines produced large quantities of waste material. The waste from tin workings, commonly referred to as 'slimes' (Dines, 1956), usually consisted of minerogenic fines (silt and clay size fractions), while other mining debris consisted of randomly assorted and fragmented lithic particles of varied particle size. Primary crushing and sorting (dressing) would produce secondary waste consisting of barren lode material or unwanted (gangue) minerals. In copper mines this often included large quantities of iron or arsenical pyrites, much of which escaped the process of calcination. Metalliferous mine waste has either remained *in situ* in sub-surface dumps or as surface spoil, or has been removed to the coastal lowlands and nearshore area via the fluvial system (National Rivers Authority, 1994). Everard (1962) has demonstrated that the silting of estuaries and bays as a result of mine waste redeposition has been evident on the Cornish coast for many years.

Data sources

Until recently, there has been little collation of documentary evidence relating to the production and disposal of mine waste sediments in Cornwall. While substantial information on the geological and mining background is available, little attention has so far been paid to mine waste redeposition in coastal lowlands. The volume of information on mine waste sedimentation currently available is small and much of what is available is of a generalised and imprecise nature.

The work reported here is based on the findings from a field pilot survey carried out by Healy (1995a). This survey examines the linkages between mine waste materials and the physical and chemical character of sediment sequences at selected sites (Figure 2) in the Cornish coastal lowlands. Field reconnaissance identified sites likely to yield sedimentary records of sufficient quality to satisfy the central aim of the project. A series of sediment cores was retrieved, wrapped and removed to the laboratory for sub-sampling and analysis. The purpose of laboratory work was to establish the concentrations of heavy metals contained within sediment sequences retrieved during field studies. Concentrated nitric acid (HNO_3) was used for sample digestion. Geochemical analysis was performed on a Philips PH7450 Inductively Coupled Plasma Spectrometer (ICP) and a Varian Spectra 250 Plus Atomic Absorption Spectrophotometer (AAS). Procedures and instrumentation used are detailed by Healy (1995a).

Results

A detailed account of site stratigraphies and the results of geochemical analysis for the sites examined is provided by Healy (1995a). The following synopsis of results indicates the physical nature of the sampled substrates and the range of heavy metal concentrations found within sedimentary sequences at the selected study sites.

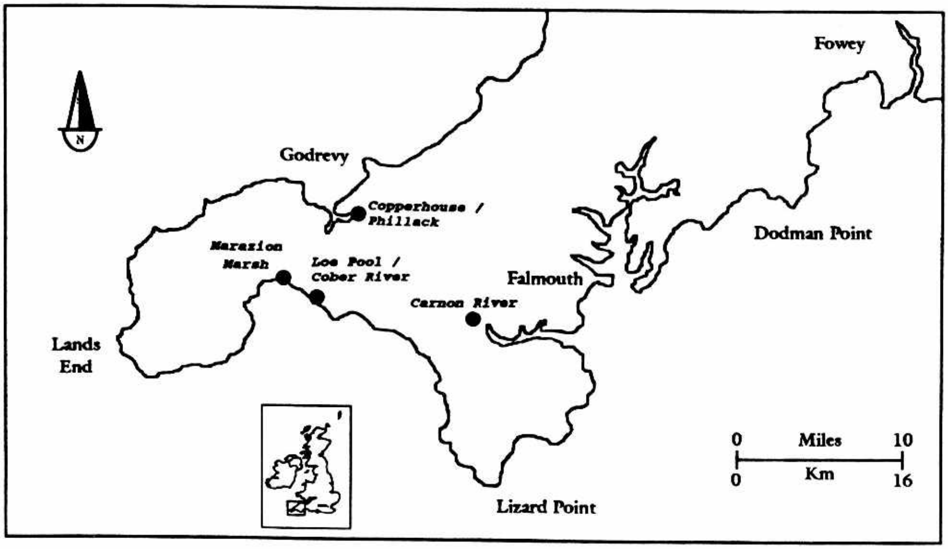

Figure 2 **Sites used for the analysis of metalliferous sediments in west Cornwall**

Loe Pool

Loe Pool (Figure 2) is a coastal lake located 1 km south of the town of Helston, Cornwall (SW 648 250). The main source of water supply to the lake is the River Cober, which drains approximately 90% of the surrounding catchment (Healy, 1993). At the point where the Cober enters Loe Pool an advanced 'silting up' has taken place. Studies reported by Simola *et al.* (1981), O' Sullivan *et al.* (1982) and Coard *et al.* (1983) show that red-brown/grey sub-laminated sediments occur in Loe Pool. These consist of 'clay-gytta' in the upper sediments underlain by 'red-grey clays'. Coard *et al.* (1983) correlate haematite-rich red-brown layers in the stratigraphy with periods of mining activity in the River Cober catchment.

Samples were taken from two points at this site: a) Loe Pool (from the lake sediment at the mouth of the gorge; and b) Cober River channel (where the river debouches into Loe Pool). The sediment sequence retrieved from the lake bottom extends from +2.27 m to -1.56 m O.D. The stratigraphy is dominated by fine minerogenic material with intermixed biogenic deposits. Concentrations of three metals were measured within the Loe Pool sediment sequence. Iron (Fe) was found to be most abundant within the upper sediment sequence. Concentrations are consistently of the order of 30,000 ppm. The greatest concentrations of copper (Cu) coincide with those of Fe but are generally of a lower order of magnitude, with a peak value of 5,000 ppm. Otherwise, Cu values are of the order of 100 to 1,000 ppm. Tin (Sn) exhibits high concentrations, with a peak of 8,500 ppm and consistently exhibits values of 1,000 ppm to 3,500 ppm. The Cober River channel sequence extends from +4.00 m to +3.26 m O.D. The stratigraphy is dominated by minerogenic material with traces of organic matter, except in the topmost 10 cm where fresh, fibrous, dark brown peat is present. Concentrations of five metals were measured. Cu values are generally less than 600 ppm, though a peak of *c.* 1,300 ppm occurs 10 cm below the present ground surface. Fe values are consistently high throughout, being in the order of 10,000 ppm or above. Concentrations of lead (Pb) range from *c.* 500 ppm to 1,000 ppm in the majority of the sequence, but rise sharply to *c.* 1,700 ppm at the ground surface. Sn concentrations show a distinct peak of c. 1,850 ppm at +3.53 m O.D. but the majority of values fall between 400 and 1,000 ppm. Zinc (Zn) concentrations are generally low throughout but rise towards the sediment surface.

Marazion Marsh

Marazion Marsh (Figure 2) lies west of Marazion village and landward of St. Michael's Mount (SW 515 298). The marsh is protected from direct marine activity by a sand and gravel barrier. The marsh has a long history of alluvial tin workings (Henwood, 1873). Stream banks reveal deposits of red-brown, fine, laminated sediments (Healy, 1993). Considerable quantities of sediment continue to pass through these streams, necessitating occasional dredging of channels to relieve back-marsh flooding. The presence of alluvial deposits in sub-marine channels in Mount's Bay has been confirmed by acoustic sounding (Goode & Taylor, 1988). Healy (1993, 1995b) has provided a detailed environmental history of the Marazion Marsh site.

Sample material was collected from the banks of the Marazion River. The sediment sequence extends from +3.45 m to +1.91 m O.D. The stratigraphy changes from sand dominance in the upper 50 cm to mainly fine minerogenic material with intermixed biogenic and sand deposits with depth. Concentrations of five metals were measured within the sediment sequence. Concentrations of Cu are generally of the order of 400 to 1,000 ppm, with a peak value of *c.* 1,900 ppm recorded. Highest Fe concentrations coincide stratigraphically with those of Cu. Values generally range from 20,000 to 30,000 ppm. Pb concentrations are of a lower order but mirror the patterns described for Cu and Fe, and Pb values rise sharply towards the sediment surface (*c.* 1,000 ppm). Sn values range from 200 to 1,000 ppm through the sequence. Values for Zn are generally lower than those for other metals at Marazion Marsh.

Copperhouse-Phillack

The River Hayle and its tributaries drain a large catchment area of the north Cornwall coast before debouching into St. Ives Bay. The southern margins of the bay are formed by the Hayle Estuary. A semi-fossilised branch of the estuary (Figure 2) lies between Copperhouse and Phillack (SW 567 382). Stratigraphic studies in this area (Healy, 1993) reveal red-brown/grey-green laminated and sub-laminated depositional layers. The sediment sequence retrieved from Copperhouse-Phillack extends from +3.46 m to +2.73 m O.D., with a peaty topsod overlying minerogenic fines at +3.36 m O.D. This gives way to medium-fine sand with an organic component before minerogenic fines dominate the stratigraphy to +2.96 m O.D. Concentrations of five metals were measured within the Copperhouse-Phillack sediment sequence. Cu concentrations generally range between 3,000 and 4,500 ppm between +2.74 m and +3.20 m O.D., with a pronounced peak of 6,300 pm. Values fall sharply within the upper sediment sequence. Fe concentrations are high throughout (*c.* 20,000 to 30,000 ppm) with values reaching c. 70,000 to 80,000 ppm in some horizons. Pb values are generally less than 1,000 ppm but are noticeably higher (2,500 to 3,000 ppm) where silt/clay dominates the stratigraphy. Sn values are generally lower than 1,000 ppm. Values for Zn show a series of peaks and troughs. Peak values exceed 3,000 ppm.

Carnon River

The Carnon River (Figure 2) drains a catchment area which spatially coincides with part of the Gwennap mining district (Dines, 1956). This area has been intensively mined in the past and environmental problems linked to waste water discharge remains a problem in areas adjacent to the river channel and in the Fal Estuary (Carnon Consolidated Ltd, 1992; Dawson, 1993). A sample core was retrieved from the floodplain of the Carnon River in the tidal stretch upstream of Restronguet Creek (SW 786 398). The sediment sequence extends from +6.30 m to +4.76 m O.D. The stratigraphy consists wholly of minerogenic fines with traces of organic debris. Sediment bands are differentiated by colour changes, but these are not indicative of lithological or stratigraphic variations. Concentrations of five metals were measured. Values for Cu generally fall within the range 4,000 to 10,000 ppm, with a prominent peak of 15,000 ppm. Fe values are very high throughout, ranging from *c.* 22,500 to 85,000 ppm in the upper horizons and reaching 127,000 ppm at +5.76 m O.D. Pb values are *c.* 800 to 1,200 ppm through the majority of the sequence, with a notable increase in the surface 10 cm where Pb values reach in excess of 10,000 ppm. Sn concentrations vary from 250 to 1,200 ppm through the sediment sequence, with a single sample demonstrating 2,000 ppm. Zn values are more variable, generally ranging from 800 to 1,800 ppm, with a well defined peak reaching 6,000 ppm between +5.20 m and +5.35 m O.D.

Defining the environmental problem

Heavy metals occur naturally but human activities in mining districts have greatly increased their concentrations, sometimes to a toxic degree. Where more than 1,000 ppm of any metal is present it is usually toxic to plants. Consequently, toxic sediments and soils remain bare and subject to erosion for many years (Thompson *et al.*, 1986). Metalliferous ore extraction results in the production of large quantities of waste material. Such waste may remain *in situ* as 'spoil', or be dispersed in drainage waters to contaminate river and coastal systems far beyond the immediate area of extraction. Metals remaining in wastes are often toxic to animals and humans as well as plants. The presence of high concentrations of heavy metals in sediments and soils gradually leads to available metal uptake by tolerant plants, thus providing a mechanism for entry into food chains/webs. Alterations in coastal wetland geochemistry affects the flora and fauna, but the nature of the problem relates to hydrological transfer routes, reactivities, sedimentation, erosion and bioturbation processes (Viles & Spencer, 1995). Understanding and managing environments in which these problems occur presents a serious challenge for coastal planning and management.

In west Cornwall, the sites studied contain sediment sequences which exhibit physical and chemical characteristics concordant with mining activity and associated redeposition of waste materials. Stratified near-surface sediments display distinctive coloration and sub-lamination. The most common visual characteristic is red-brown mottling (Marazion Marsh, Cober River) and grey-green coloration (Marazion Marsh, Copperhouse-Phillack, Loe Pool). Frequently, colour changes are associated with other physical alterations, in particular particle size (Marazion Marsh, Copperhouse-Phillack). Spatially continuous lamination is rare, possibly suggesting an irregular topography in depositional areas linked to variation in water and sediment throughflow, with 'pulses' of mine waste materials reaching coastal areas through time. Geochemical analysis of samples from sediment sequences with these characteristics reveal that concentrations of heavy metals commonly exceed toxic levels in west Cornwall. Studies published by Abrahams & Thornton (1987), Johnson & Thornton (1987), Brown (1977) and Yim (1976) support this conclusion.

At present, the majority of contaminated sediments remains inactive except in exceptional circumstances, such as the Wheal Jane flood of January 1992 (Dawson, 1993). However, as these deposits occur in potentially high energy coastal, riverine and estuarine locations, there is a considerable likelihood of anthropogenic and/or geomorphological disturbance in the future. Site development, building works, engineering projects and infrastructure improvements have the potential to remobilise mine waste materials. Additionally, geomorphologically induced coastal change, linked to relative sea-level movements (Healy, 1995b), may provide a mechanism for redistribution of contaminated sediments. In the absence of more widespread and detailed surveys the consequences of such disturbance for human health and nature conservation remain unknown.

The coastal management response

At present, there is no comprehensive data on the extent of contaminated land in the UK. While individual organisations are concerned about specific environmental problems linked to land contamination (e.g. the National Rivers Authority initiatives on water quality in Devon and Cornwall), co-ordinated management of areas affected by particular contamination sources remains absent. The evidence presented in this paper suggests that there are significant actual or potential environmental problems linked to land contamination by metalliferous mine waste redeposition in some coastal areas of west Cornwall. This has clear implications for the management of depositional sites at or adjacent to coastal areas. As the majority of such sites take the form of coastal wetlands, marshes, lagoons, estuaries and river floodplains, the potential for contamination of ground and surface water is important. In addition, flora and fauna have limited and specific tolerance thresholds for the uptake of heavy metals, the presence of which will consequently limit biodiversity and constrain the biological resource. Hart & Lake (1987) have summarised several Australian studies which illustrate the risk of heavy metal contamination to human health and wildlife. In a specific study of tin mining and coastal pollution, Chansang (1988) details the environmental consequences of alluvial mining for casserite on the coast of Thailand which has been detrimental to the physical, chemical and biological balance of coastal ecosystems.

While the nature of the problems described may generate serious environmental degradation, solutions which could ameliorate or prevent the most serious consequences of heavy metal contamination have been devised and employed successfully in some mining districts (Bradshaw, 1984). Addressing the problems of the west Cornwall coast remains primarily a question of co-ordinated surveying, data collation and effective environmental management.

The main requirements are:

1. An integrated and comprehensive quantitative survey of sites which are, or may be, affected by heavy metal contamination.
2. An assessment of disturbance risk for individual sites.
3. An evaluation of current technologies for treatment and rehabilitation of sites subject to contamination.
4. A planning and management strategy which takes account of actual and potential risks associated with heavy metal pollution.
5. A forum representing interested organisations and individuals to assess the problem of metalliferous mine waste deposits and to co-ordinate appropriate action.

Conclusions

Geochemical data shows that the sediment sequences from each of the study sites examined demonstrate concentrations of heavy metals of an order in excess of that which may be expected from normal precipitation and weathering processes. These sequences appear to be the product of mine waste release and redeposition, with variations in the concentrations of heavy metals representing distinctive geochemical signatures. It is possible that any future large scale disturbance of these deposits may have a detrimental environmental impact due to heavy metal contamination of substrates as well as groundwater and surface water. Specific conclusions may be summarised as follows:

1. A useful literature which deals with the history of mining in Cornwall is available, though this varies in quantity and quality among sites.
2. Depositional sites in the Cornish coastal lowlands contain sediment sequences which are visually and physically distinctive and correlate well with documented descriptions of metalliferous mine waste materials.
3. Geochemical analysis shows that sediments contain unusually high concentrations of heavy metals (Fe, Cu, Zn, Pb and Sn) which correspond with past mining activity in adjacent areas and mine waste release and redeposition in coastal and riverine areas.
4. Further studies on physiographic conditions in these environments may reveal the potential impact of disturbance of these sediments on the coastal resource.
5. A co-ordinated planning and management response is necessary to respond to the problem of heavy metal contamination.

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References

Abrahams, P.W. & Thornton, I. 1987. Distribution and extent of land contaminated by arsenic and associated metals in mining regions of south west England. *Transactions of the Institution of Mineralogy and Metallurgy, (Sect. B: Applied Earth Science)*, 96:B1-B8.

Bradshaw, A.D. 1984. Land restoration: now and in the future. *Proceedings of the Royal Society of London*, B223:1-23.

Brown, B.E. 1977. Effects of mine drainage on the River Hayle, Cornwall. A) Factors affecting concentrations of copper, zinc and iron in water, sediments and dominant invertebrate fauna. *Hydrobiologica*, 52:221-233.

Carnon Consolidated Limited. 1992. Information Regarding the Discharge of Mine Water from the Gwennap Mining District into the Carnon River. Carnon Consolidated Limited, P.O. Box 2, Truro TR3 6EH, Cornwall.

Chansang, H. 1988. Coastal tin mining and marine pollution in Thailand. *Ambio*, 17:223-228.

Coard, M.A., Cousen, S.M., Cuttler, A.H., Dean, H.J., Dearing, J.A., Eglinton, T.I., Greaves, A.M., Lacey, K.P., O' Sullivan, P.E., Pickering, D.A., Rhead, M.M., Rodwell, J.K. & Simola, H. 1983. Palaeolimnological studies of annually - laminated sediments in Loe Pool, Cornwall, U.K. *Hydrobiologia*, 103:185-191.

Dawson, T.P. 1993. Using GIS for the classification of contaminated land in association with water quality protection. In: *Proceedings of GIS for Environment Conference, Krakow, 25-27 November*. Geographical Information Systems Laboratory, Institute of Geography, Jagiellonian University, Krakow, Poland. pp. 63-69.

Dines, H.G. 1956. The Metalliferous Mining Regions of South West England. *Memoir of the Geological Society of Great Britain*. HMSO, London.

Everard, C.E. 1962. Mining and shoreline evolution near St. Austell, Cornwall. *Transactions of the Royal Geological Society of Cornwall*, 19(3):199-219.

Goode, A.J.J. & Taylor, R.T. 1988. *Geology of the Country Around Penzance*. Memoir of the Geological Society of Great Britain (for the 1:50 000 Geological Sheets 351 and 358 England and Wales). HMSO, London.

Hamilton-Jenkin, A.K. 1961-1965. *Mines and Miners of Cornwall*. D. Bradford Barton Limited, Truro, Cornwall, UK.

Hart, B.T. & Lake, P.S. 1987. Studies of heavy metal pollution in Australia with particular emphasis on aquatic systems. In: *Lead, Mercury, Cadmium and Arsenic in the Environment*. Eds: Hutchinson, T.C. & Meena, K.M. Wiley, Chichester. pp. 187-216.