'Occupational Exposure to Heavy Metals Poisoning: Scottish Lead Mining'

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The study examines historic occupational lead poisoning (occupational plumbism) amongst the mining labour force at Tyndrum lead mine in the Scottish southern highlands in the eighteenth and nineteenth centuries set against the backdrop of the wider national context. Traditional archival research is combined with environmental science to both identify incidence of poisoning and the historic health risk factors that were specific to the industry, particularly at the surface of the mine. Emphasis is placed upon employment practices, technology and wider social conditions such diet and alcohol and the toxicity of the different compounds of lead (mineralogy) that the workers were exposed too.

Introduction

From around 3500BC onwards lead has been highly valued for its malleable, ductile, and non-corrosive properties and also its ability to combine readily with other metals to form alloys.[1] Historically the uses of lead have been many and varied, including cooking pots, coffins, water piping and decorative objects; as well as a sweetening agent, cosmetics, an abortifacient, a spermicide pigment in paints and ceramic glazes also for radiation shields, in batteries; ammunition and as an additive in petrol. Yet the metal also has a long history of recognition as a harmful to all life and an association with occupational ill health particularly amongst the white lead, pottery and earthenware trades.[2]

Lead is an accumulative poison and is stored in bone where it has 'an extremely long half-life', and in teeth where it hinders mineralisation of tooth enamel and is associated with

[1] H. A. (Tony) Waldron, 'Lead Poisoning in the Ancient World', *Medical History*, 17, 4 (1973) 391-399, 391.

[2] In terms of toxicity see Jerome O. Nriagu, *Lead and Lead Poisoning in Antiquity*, (New York: Wiley, 1983) and for occupational association see Peter W. J. Bartrip, *The Home Office and the Dangerous Trades: Regulating Occupational Disease in Victorian and Edwardian Britain*, Clio Medica 68 (Amsterdam: Editions Rodopi, 2002), pp. 11-13.

increased incidence of dental caries. The common pathways of human contamination are primarily ingestion and inhalation and potentially some absorption through the skin.[3] The rate and extent to which a substance reaches systemic circulation (bio-availability) is mediated by a variety of factors, such as particle size, solubility of the lead compound (mineralogy), standards of hygiene, length of exposure, age and nutritional intake.[4] Children are particularly susceptible to poisoning; they absorb around 42% of ingested lead and retain around 32% compared to 5-15% absorption and 5% retention in adults.[5] In terms of diet, fat and some vitamins hinder, whereas alcohol, for example, aids absorption.[6]

Symptoms of lead poisoning include gastro-intestinal disturbance, characterised by abdominal cramps, nausea, vomiting and constipation; anorexia; insomnia; fatigue; irritability; mood disturbance; muscle weakness and loss of co-ordination. Chronic exposure to the metal, even at low levels, damages the nervous, renal, cardio-vascular and blood forming systems, leading to, for example, cognitive impairment, neurological disability and an increased risk of some cancers.[7] In women specifically, poisoning can result in gynaecological problems such as menstrual disorders, spontaneous abortion and an increased risk of still birth. Yet despite its toxicity the metal continued to be regularly used up until the late 20th century in paints, plumbing and as an additive in petrol, and is currently still used in batteries, radiation shields, undersea cabling and for roofing on historic buildings.

There is a fairly substantial body of literature on historical occupational and environmental exposure to lead. The focus is largely polarised between those studies which emphasise the experiences and understanding of the various interests, such as the

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[3] Lead is poorly absorbed through the skin. Paul Mushak, *Lead and Public Health: Science, Risk and Regulation* (Oxford: Elsevier, 2011) p. 254.

[4] Jack E. Fergusson, *The Heavy Elements: Chemistry, Environmental Impact and Health Effects* (Oxford: Pergamon, 1990), p. 511-522.

[5] Curtis D. Klaassen (Eds.), *Casarett and Doull's Toxicology: The Basic Science of Poisons Seventh Edition* (New York: McGraw Hill, 2008) p. 944.

[6] Thomas M. Legge & Kenneth W. Goadby, *Lead Poisoning and Lead Absorption: The Symptoms, Pathology and Prevention,* (London: Edward Arnold, 1912) p. 37, A. G. Shaper et. al. 'Effects of Alcohol and Smoking on Blood Lead in Middle-aged British Men', *British Medical Journal*, 30th January 1982, 299-304, Stephen Davies and Alan Stewart, *Nutritional Medicine* (London: Pan MacMillan, 1987) p. 96 and also see Robert J. Taylor, 'Food, Nutrition and Lead Absorption', Review Article*, Lead Action News*, 10, 2, (2010) 1-41.

[7] See Klaassen, *Basic Science of Poisons,* pp. 943-47 for details of the effects of lead on the human body.

physicians and the policy makers, and the relationships between the involved parties. Some key examples here are the early classic works by British physician and authority on industrial disease, Sir Thomas Oliver and also Alice Hamilton, physician and progressive era reformer.[8] Historian Christopher Sellers has explored poisoning from the perspective of both the physicians and the policy makers in *Hazards of the Job: From Industrial Disease to Environmental Health Science* published in 1997, and more recently Bartrip has studied the regulation of the 'dangerous trades' (working with lead was one the first four recognised 'dangerous trades') from bureaucratic and parliamentary perspectives.[9]

The corresponding emphasis is on the sufferer. Increased susceptibility to poisoning ensured that children and women were prominent as victims. The focus on paediatric poisoning is largely grounded in the 20th century North American experience of environmental exposure to both airborne lead from vehicle exhausts; the so called 'silent epidemic' and from lead based paint. Recent examples here are Gerald Markowitz and David Rosner, *Lead Wars, and* Peter C. English, *Old Paint*.[10] Christian Warren, in *Brush with Death* successfully combines environmental, paediatric and occupational exposure, again in the US context.[11] Historic exposure to lead amongst women workers, particularly from a British perspective is dominated by studies of the white lead and the pottery and earthen-ware trades. Female labour in these industries was the focal point of government intervention, and the history of regulation has attracted gendered narratives. Key examples here are Barbara Harrison, *Not Only the Dangerous Trades: Women's Work and Health in Britain* and Caroline Malone, *Women's Bodies and the Dangerous Trades in England*.[12] There is however very little research on occupational plumbism amongst the labour force

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[8] For example see Thomas Oliver Lead *Poisoning: From the Industrial, Medical and Social Points of View*, (London: Lewis, 1914) and Alice Hamilton*, Industrial Poisons in the United States* (New York: Macmillan, 1925).

[9] Bartrip, *Home Office and the Dangerous Trades.*

[10] Gerald Markowitz and David Rosner, *Lead Wars: The Politics of Science and the Fate of America's Children* (Berkley: University of California Press, 2013) and Peter C. English, *Old Paint: A Medical History of Childhood Lead-Paint Poisoning in the United States to 1980* (New Brunswick: Rutgers University Press, 2001).

[11] Christian Warren, *Brush with Death: A Social History of Lead Poisoning* (Baltimore: John Hopkins University Press, 2000).

[12] Barbara Harrison, *Not Only the Dangerous Trades: Women's Work and Health in Britain* (London: Taylor and Francis, 1996) and Caroline Malone, *Women's Bodies and the Dangerous Trades in England* (Woodbridge: Boydell, 2003).

who worked with the raw material; the lead ore. Underground and surface labour, particularly at the dressing floor, as Nriagu points out, 'handled it, inhaled it and ingested it', 'in short' he comments, they 'wallowed in it'.[13] Lead ore required dressing (processing) before smelting. The ore was initially washed and then it was repeatedly crushed or milled and separated from the waste rock hydro-dynamically either by sieving or buddling (separation by gravity in water). The lack of occupational health history is surprising given that the dressing floors were similarly dominated by women but particularly children who were at greater risk of exposure.

Occupational health histories of mining labour have been characterised by an emphasis on accidental injuries and their prevention in the underground working environment, particularly in the coal sector.[14] Whilst there has been some recent interest in occupational diseases amongst both coal and metal miners, the focus to date has largely been on the unhealthy underground environment and on the pneumoconioses (of which silicosis was the common cause of death amongst metal miners) and ankylostomiasis, a parasitic infection of the small intestine classified as industrially generated and compensatable in 1906.[15]

Whilst there are no comprehensive studies on historic occupational plumbism amongst mine labour and knowledge is sparse there are isolated references in the literature indicating that exposure to lead amongst all three classes of labour, miners, ore dressers and smelters, may have been problematic. What is not known is the extent to which these were isolated incidences or evidence of a wider problem. Burt in his history of the British lead mining industry briefly comments on the increased risk of occupational plumbism for miners from sustained contact with wet and contaminated work clothing.[16] There are also some early observations in the US context, McCord suggests a high incidence of poisoning

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[13] Nriagu, *Lead and Lead Poisoning in Antiquity*, p. 311.

[14] For example see Arthur McIvor and Ronald Johnston, *Miners' Lung: A History of Dust Diseases in British Coal Mining* (Aldershot: Ashgate, 2007.

[15] For example see Gillian Burke and Peter Richardson, 'The Profits of Death: A Comparative Study of Miners' Phthisis in Cornwall and the Transvaal 1876-1918', *Journal of South African Studies*, 4, 2 (1978), 147-171 and Catherine Mills, 'The Emergence of Statutory Hygiene Precautions in the British Mining Industries, 1890-1914', *Historical Journal*, 51, 1 (2008), 145-168.

[16] Roger Burt, *The British Lead Mining Industry*, (Redruth: Dyllansow Truran, 1984) p. 191.

amongst hard rock silver miners in Utah and Colorado from the last quarter of the nineteenth century onwards.[17] He estimates that between 1882 and 1902 the Bullion-Beck and Eureka Hill mines were responsible for poisoning over 6,000 miners, and he also notes that every 'tram mule' died within a year of purchase.[18]

Most regional British histories make reference to the hazards of smelting heavy metals. Early smelt mills consisted of a hearth and a short stack. They were inefficient and dirty; discharging fumes within the immediate environment of the hearth. The fumes were particularly hazardous because of their small particle size. For example, Hunt in his study of lead miners in the Northern Pennines opens a window onto the 'unwholesome' conditions at Langley Mill where tenants were enticed with free rent and fuel to occupy the cottages adjacent to the smelter.[19] Turnbull also draws attention to the loss of livestock including horses, ponies, cows and sheep at the neighbouring farm which resulted in a payment of £175 compensation in 1779.[20] Hamilton has similarly drawn attention to problems of poisoning in the US western mining districts and amongst lead smelters and refiners working at the surface of the mines.[21]

In terms of surface labour, there are far fewer references in the literature to the ore dressers. Burt, noted that the increased exposure from work clothing applied equally to surface workers as well as miners.[22] Mayers has dedicated a short chapter on occupational health and mortality in her study of Cornish bâl maidens, who dressed copper and tin ore for smelting and likewise Schwartz and Parker have discussed wider social and working conditions in their study of the Cornish mining Parish of Lanner.[23] Myers, in particular, has suggested that heavy metals poisoning particularly from arsenic, did occur. 'Mundic water', water contaminated with iron, copper and arsenic, was alleged to have caused

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[17] C. P. McCord, 'Lead and Lead Poisoning in Early America: Lead Mines and Lead Poisoning', *Industrial Medicine and Surgery*, 22, 11 (1953) 534-539.

[18] Ibid. 535.

[19] Christopher J. Hunt, *The Lead Miners of the Northern Pennines*, (New York: A. M. Kelley, 1970) p. 142.

[20] Les Turnbull, *The History of Lead Mining in the North East of England*, (Hexham, Ergo, 2008) p. 67.

[21] Hamilton, *Industrial Poisons in the United States* and Alice Hamilton 'Lead Poisoning in the Smelting and Refining of Lead', *Bulletin of the United States Bureau of Labour Statistics*, 114, (1914) 1-97.

[22] Burt, *British Lead Mining*, p. 191.

[23] Lynne Mayers, *Balmaidens* (Penzance: Hypatia, (2004) pp. 131-150 and S. Schwartz & R. Parker, *Lanner, A Cornish Mining Parish* (Tiverton: Halsgrove, 1998) pp. 85-91.

gynaecological problems amongst the women surface workers at Wheal Vor and arsenic dust was recognised as causing skin rashes around the mouth, ankles and wrists of the women and also when it became trapped in folds of skin. She also comments that mining management paid little attention to the fact workers laboured with, and in close proximity to, hazardous substances.[24] The methods and machinery for the separation of all metalliferous ores was similar and it is likely that the lead ore dressers suffered similar risks of exposure.[25]

Whilst the primary aim of this study is to increase the knowledge and understanding of the risk of occupational exposure to lead and incidence of poisoning amongst mining labour, it was initiated by a recent landscape biography of an abandoned lead mine site at Tyndrum, Stirlingshire in the southern Scottish highlands. This project examined the relationship between historic mining and pollution and suggested that there is a clear association between environmental lead values and the quantity of ore extracted at the mine rather than with a particular period or technological innovation in the history of mining at the site. A similar relationship between production and pollution has also been previously established at Leadhills mine, Scotland's largest producer of lead ore, located in the southern uplands.[26] The Tyndrum study also indicated that of the three processes carried out at the mine; extraction, ore dressing and smelting, it was the dressing processes that consistently generated the highest lead concentrations within the mine environment. Current lead values were in some instances 200 times greater than background levels. [27]

The landscape biography of the Tyndrum mine site raises several key questions for the study of historic occupational plumbism. Did the pollution production correlation follow through into health? McCord has suggested that the number of poisoning cases in the US context directly reflected production at the mine.[28] It makes a certain amount of logical

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[24] Mayers, *Balmaidens*, p. 138.

[25] Roger Burt, *A Short History of British Ore Preparation Techniques in the Eighteenth and Nineteenth centuries* (Netherlands: De Archaeologische Pers, 1982) p. 5.

[26] John S. Rowan, *et al*., 'Geomorphology and pollution: the environmental impacts of lead mining, Leadhills, Scotland', *Geochemical Exploration*, 52 (1995) 57–65.

[27] Catherine Mills, Ian Simpson and William Paul Adderley, 'The Lead Legacy: The Relationship Between Historical Mining, Pollution and Post-mining Landscapes', *Landscape History*, 35, 1, (2014) 47-72.

[28] McCord, 'Lead and Lead Poisoning', 534-539, 534.

sense that during periods of increased ore extraction, productivity at the dressing floor and smelt mill would also have increased and the workforce would be at greater risk of exposure to the heavy metal. Moreover, although there are very few references in the literature to poisoning amongst the ore dressers, this class of mine labour created and had regular contact with higher environmental values. So was their risk of exposure moderated in some way by the factors that mediate absorption such as dose, bio-availability and duration of exposure? Whilst this study seeks to answer these questions, more broadly it also examines the value of the environmental record in the exploration of historic risk and incidence of occupational plumbism; can the present lead legacy help in the understanding of the problems of the past?

This study returns to Tyndrum mine and its workforce in the eighteenth and nineteenth centuries. This will allow linkage between the current environmental record at the site and historic health events. Moreover the historic pattern of development and operation at the mine reflects the British context. For example the pattern of alternating periods of activity and idleness and attendant changes in the ownership of the mineral rights in response to fluctuating ore prices on the world market; the pyramidal structure of the industry where a few large mines produced the majority of Britain's output and were supported by a greater number of medium-sized ventures and an even greater number of small mines, such as Tyndrum that operated on the margins of the industry; the pre-industrial model of dual labour adopted by the workforce who both mined and farmed; the absence of women employed underground and the application of similar technologies, such as water and later steam power as mining industrialised.[29] These similarities permit wider conclusions to be drawn. The focus on a Scottish venture also helps plug yet another gap in the literature. In comparison to the history of English and Welsh metal mining, study of the industry north of the border is very sparse and largely confined to T. C. Smout's chapter on the economic history in the period 1650 to 1850.[30]

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[29] Mills, Simpson and Adderley, 'The Lead Legacy', 47-72, 50. Also See Burt, *British Lead Mining*, pp. 1-9

[30] Thomas Christoper Smout, 'Lead-mining in Scotland, 1650-1850' in P. L. Payne, (ed.) *Studies in Scottish Business History* (London, Cass, 1967) pp. 103-135. There are a variety of short individual mine and regional histories for example R. M. Callender and J. Macaulay, 'The Ancient Metal Mines of the Isle of Islay, Argyll', *British Mining*, 24 1(984) 1-46; Michael Cressey, John Pickin and K. Hicks, 'The Silver Rig, Pibble and Woodhead Metal Mines,

Unfortunately mortality and morbidity data is extremely sparse for the period both at Tyndrum and in the wider context. Whilst this renders a quantitative analysis impossible there is an abundance of qualitative evidence. Extensive records exist for the Scots Mining Company (hereafter SMC) who leased the mineral rights at Tyndrum from 1768 to 1791 and the landowners, the Campbell family of Breadalbane.[31] The second marquis of Breadalbane also worked his own mineral rights between 1832 and his death in 1862, primarily under the management of German mine engineers who produced regular and extensive reports that open a window on not just geology, technology and mining practices but also on health and social conditions at the mine. In addition the study draws heavily on eighteenth century travellers and writers, such as Thomas Pennant who toured Scotland in 1769, for their general observations on the mining communities.[32] Specifically for the nineteenth century, there are two key Royal Commission inquiries that also offer insights into the occupational health and welfare of the mining labour in the national context; the 1842 *Report of the Commissioners on the Employment of Women and Children in Mines* (hereafter *Children's Employment Commission*) and the 1864 *Report of the Commissioner's Appointed to Inquire into the Condition of All Mines to which the Provisions of the Act 23 & 24 Vict. c. 151 Do not Apply* (hereafter *Kinnaird Commission* after the title of its chair).[33]

The documentary evidence is combined with existing environmental and geo-archaeological studies, and also environmental chemistry to explore the question of bioavailability in understanding historic risk factors and the incidence of poisoning. The environmental record acts as an additional primary source. The soil material witnessed the development operation and subsequent abandonment of the mine and scientific analysis

Galloway, Scotland', *Mining History*, 15, 6 (2004) 49-62 and Stephen Moreton, 'The Lead Mines of Tyndrum', *British Mining*, 99 (2015)1-135.

[31] Scotch Mines Company Journals, DK/7.28/ Centre for Research Collections, University of Edinburgh (hereafter SMC) and Breadalbane Muniments, GD112/ National Records of Scotland (hereafter NRS).

[32] Andrew Simmons (ed.) *A Tour in Scotland and Voyage to the Hebrides 1772 by Thomas Pennant* (Edinburgh: Birlinn, 1999)

[33] BPP *Report of the Commissioners on the Employment of Women and Children in Mines*, 1842 (380) (381) (382) hereafter *Children's Employment Commission* and BPP *Report of the Commissioner's Appointed to Inquire into the Condition of All Mines to which the Provisions of the Act 23 & 24 Vict. c. 151 Do not Apply* , 1864, Report, Evidence and Appendices (3389) hereafter *Kinnaird Commission.*

simply gives it a voice. Comparisons are drawn with Leadhills mine and the discussion is grounded in the wider national context.

The integrated study takes the reader on a problem solving journey of false starts and blind alleys before concluding that occupational plumbism occurred across all underground and surface mining occupations, yet despite exposure to exceptionally high levels of bio-available lead in the working environment, particularly at Tyndrum, incidence of poisoning was often absent or at low level and scattered and bears little association to the production pollution relationship. Although it proved impossible to establish the full extent of suffering due to observational biases, lack of medical understanding and difficulties in diagnosis, recorded incidences correlate more persuasively with the length of time the workforce were exposed to the contaminated environment. Moreover, this exposure was minimised by a variety of protective influences that were in operation, by default rather than by design, in the working environment. These included material factors such as diet and weather conditions, technological considerations such as the adoption of long chimney flues and application of mechanical power and social conditions, such as patterns of employment.

<u>Scottish lead mining and Tyndrum mine</u>

Although lead ore has a wide distribution and was mined in almost every Scottish shire, the nation was not a major producer.[34] From the second half of the seventeenth century only six locations sustained intermittent activity; Islay, Leadhills, Minigaff, Strontian, Wanlockhead and Tyndrum.[35] The development and operation of Tyndrum mine has been documented elsewhere and only a brief history is offered below in order to contextualise the social conditions and health of the workforce.[36] Tyndrum mine is located on the northern flanks of Stron Nan Colon (known as Minehill) at an altitude of between 200 to 500m to the west of Tyndrum village in Stirlingshire, (formally highland Perthshire). In spite of a promising start the lead ore was not proven at depth and dwindling production across time can be clearly discerned in table one below. Mineralisation was complex and this hindered efficient

[34] See G. V. Wilson, *Memoirs of the Geological Survey, Special Reports on the Mineral Resources of Scotland (17) Lead, Zinc, Copper and Nickel Ores of Scotland* (Edinburgh: HMSO,1921) p. 2 and Smout, 'Lead Mining in Scotland', p. 103.

[35] Smout, 'Lead Mining in Scotland', p.105.

[36] Moreton 'Lead mines of Tyndrum'.

extraction and processing. Production was further hampered by the isolated location which thwarted economic transportation of lead, (ore and metal) to market and a supply of coal in to the site which effectively rendered the operation reliant on peat for fuel and water for power for most of its history. The mine operated at the margins of the industry. To give an indication of the declining profitability, the second marquis, between 1837 and 1856, spent around £30,500 on the operation of the mine, whilst income for the same period only amounted to around £8,500 making a total loss of £24,150.[37]

In spite of the obstacles the mineral rights were intermittently leased from 1730 through to 1928 by a variety of mining companies (see table one). Ore was initially hand dressed at the site in rudimentary shelters and smelted at Dalree located roughly 3 kilometres east of the mine. During their lease the SMC rebuilt the smelter which had fallen into disrepair and introduced mechanical hammers at the foot of Minehill to assist hand dressing and overcome the increasingly complex mineralisation. During the nineteenth century the second marquis agreed to the construction of a secondary dressing floor with water powered crushing mill and a buddling system (a process of separating the ore from waste suspended in water by gravity) at Glengary situated roughly 1.5 kilometres east of the main site. Ore at this point in the history of the mine was sold on the Welsh market and smelted off-site.

Table One Tyndrum Lead Mine 1730 to 1930

Date	Mineral Lease	Manager	Lead Production (Imperial tons)
1916-1928	Tyndrum Lead and Zinc Company		27.5
1865 -	Tyndrum Mining Company		0
1838 -1862	Second Marquis of Breadalbane	Gustav Thost Robert Harrison Sigmund Reichendorf Herr Odernheimer George Barron	25
1803 - 1807	Caledonian Mining Company		Not recorded
1768 -1791	Scots Mining Company (SMC)	James Stirling	153

[37] Figures calculated from Figure 1 Breadalbane Mineral Trials, 1837-56: Income and Expenditure cited in C. J. A. Robertson, 'Railway Mania in the Highlands: The Marquis of Breadalbane and the Scottish Grand Junction Railway' in Roger Mason & Norman Macdougall (eds.) *People and Power in Scotland: Essays in Honour of T. C. Smout* (Edinburgh: John Donald, (1992) pp. 189-217, 192.

1760 - 1762	Patton and Richardson		157
1760	Rippon Company		165
1745- 1760	English Company of Mine Adventurers		136
1730 -1745	Sir Robert Clifton		424

The mine after lying idle for around fifty years after the death of the second marquis in 1862, was leased in 1916 for surface re-processing for lead and zinc blende together with some underground exploration and this period of operation marked the final period of activity at the site. The Tyndrum Lead and Zinc Company were able to take advantage of the Oban to Callender railway which had reached Tyndrum in 1873 and invested in a steam powered crushing mill located at the base of Minehill. Transport was also improved within the site with the introduction of a self-acting plane and a rail spur to the main line. The mine was formally abandoned in 1928 and the company dissolved in 1929.

Lead and labour

Around 140 hands were employed at the mine at its peak and were primarily drawn from the wider Campbell estate, by the nineteenth century this had dwindled to around 60.[38] The men worked a bargain system negotiated every six months that was similar to the Welsh and English sectors, in two eight hour shifts beginning at 4 am and midday.[39] This was reduced to six hours during the SMC lease, surface labour worked longer shifts, around 12 to 14 hours for the smelters.[40] Bargains were for raising ore, driving per fathom or washing and dressing ore or a combination of raising, washing and dressing. By the early 1840s a miner's weekly wage was around seven shillings, this compared unfavourably with national context where the weekly wage fluctuated around fifteen shillings.[41]

Also similarly to the industry south of the border no women were employed underground.[42] As part of the commercialisation of the Campbell estate in the eighteenth century, the first marquis brought in wool workers to teach the wives and daughters of his

[38] SMCJ DK7.28.

[39] SMCJ DK7.28.

[40] See Moreton, 'Lead Mines of Tyndrum', 58 and Mary Easson, 'Environmental Degradation and the Lead Industry at Tyndrum, Scotland 1739-1930' M.Res Environmental History, University of Stirling, 201, p. 74.

[41] NRS GD112/18/8/7/20 and Burt, *British Lead Mining*, p. 164'

[42] Burt, *British Lead Mining,* p.136'

tenants spinning and weaving skills, and flax was also cultivated for the production of linen.[43] Although the names of the widows of three miners appear in the SMC's bargain books in 1790, James Stirling, the SMC manager subsequently ordered their removal and they were probably employed in ore dressing or 'wheeling out'.[44] In terms of surface labour, juvenile females were employed alongside young boys, but this practice was actively discouraged by the German managers from the early 1840s.[45] Of the 140 workers at the mine in the eighteenth century two were recorded as smelters, 40 were employed as 'washers' along with 35 surface labourers, unfortunately no breakdown by age or gender is recorded.[46] During the nineteenth century operations, roughly 20 males under 15 years of age sorted, washed and sieved small ore and slimes, and around 14 males aged between 15-20 years separated and crushed the larger rock pieces with by hand before processing at the crushing mill.[47]

At the dressing floor the workforce were continually exposed both to lead laden dust from breaking and crushing rock and from contaminated water. [48] They were fortunate at Tyndrum that the smelt mill was located roughly three kilometres downwind of the mine. Surface labour did however work in close proximity to the wastes. Technological innovations in smelting from the late eighteenth century demanded progressively smaller reductions of the ore, this resulted in finer waste 'slimes' or tailings and increased the risk of exposure. There was also no environmental protection until the mid-twentieth century and mining companies could extract the ore and dump heavy metal laden waste without restriction. Contaminated water was simply returned to source, and the slimes were spaded from the buddles into heaps and allowed to accumulate randomly around the dressing floor.[49] These eventually dried out and became vulnerable to wind erosion.

Yet in terms of general health and wellbeing, the population of Tyndrum in the 1790s was described in the *Old Statistical Account* as 'very healthy' and this was attributed to their

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[43] Easson, 'Environmental Degradation', p. 19.

[44] SMCJ DK.7.283.

[45] NRS GD112/18/8/7/18 and GD112/18/7/2/3.

[46] Moreton, 'Lead Mines of Tyndrum', 15.

[47] NRS GD112/18/8/7/18 and GD112/18/9/2/3.

[48] For discussion of the processes involved see Burt, *History of British Ore Preparation Techniques.*

[49] Easson, 'Environmental Degradation', p. 38.

'sober' as well as their 'industrious lifestyle'. A lifespan of seventy to eighty years was not unusual. The common illnesses amongst the population were noted as pleurisy and rheumatism and these were attributed to the cold damp climate rather than to occupation.[50] By 1838 the picture was much bleaker, the miners' cottages were described as being in a miserable state and needing much repair.[51] A lack of cleanliness in the home and habits was also recorded and the settlement was plagued with outbreaks of infectious diseases particularly amongst the children.[52] Overcrowding had also become a problem with 173 people squeezed into 39 dwellings.[53] Of those households, around nine also accommodated lodgers, a practice encouraged by the marquis to meet the increased demand for labour at the mine.[54]

A study by Easson in 2011 that compared Census data with statutory death certificates for the period 1841 to 1925 amongst Tyndrum residents largely upholds the original observation of longevity. Seven of the 36 inhabitants that Easson traced in the records lived well into their eightieth year, four of whom were recorded as miners and one as an ore dresser. [55] The annual average rate of accident mortality at the mine was around 0.5 per 1000 men this was significantly lower than the estimated rate of 6 per 1000 Cornish tin and copper miners and 2 per 1000 northern lead miners in roughly the same period.[56] What is clear from Easson's analysis is the prevalence of respiratory diseases, such as phthisis, asthma, consumption and bronchitis, amongst the inhabitants who were or had been employed at the mine. Although the Tyndrum miners rarely died young, the incidence of chronic respiratory diseases parallels incidence of disease amongst British metal miners in the period.[57]

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[50] *Old Statistical Account of Scotland,* 1791-99, Volume 17, Killin, County of Perth, p. 372.

[51] NRS GD112/18/8/7/2 & 6.

[52] NRS GD112/18/9/7/13.

[53] For the period 1841 to 1881, Calculated from the Census records by Mary Easson, See Easson, 'Environmental Degradation' p. 77.

[54] NRS GD/112/18/8/7/6.

[55] See note 53 above.

[56] Tyndrum data calculated from recorded accidents in the period 1838-1862, NRS GD112/ and Catherine Mills, *Regulating Health and Safety in the British Mining Industries*, (Farnham: Ashgate, 2010) p. 25.

[57] See Table 5.2 Common Causes of Death, 1849-1853, cited in Mills, *Regulating Health and Safety*, p. 133

There are two death certificate entries that tentatively indicate chronic lead poisoning, dropsy (oedema) and particularly palsy, (paralysis) in a relatively young miner of 45 years of age. There is however no additional evidence to support this assumption, excepting an isolated brief episode of acute poisoning amongst the smelters in 1784, 'who were out of health for a week' and an isolated comment in the same year by contemporary traveller De Saint Fond of the 'unwholesome vapours' that troubled the hamlet, the records are silent.[58] Whilst Tyndrum was visited by such as Pennant and Gilpin, and their accounts reveal much about the inn and the local topography, Gilpin for example notes that Tindrum [sic] was the highest inhabited settlement in Scotland. [59] There are no descriptions of symptoms suggesting lead toxicity, such as colic, constipation, weight loss, fatigue, pallor, anorexia or peripheral neuropathy, amongst the mining population, neither were any concerns raised regarding health risks in relation to the contaminated waste that was accumulating at the surface of the mine. The Parochial Board Minutes similarly reveal very little, indicating that the health of the population was 'perfectly satisfactory'.[60] Likewise the Medical Officer of Health, following his appointment in 1891, described Tyndrum as 'dilapidated' and he was concerned with the frequent outbreaks of measles and smallpox amongst the navies constructing the railway.[61]

This contrasts markedly with the lead mining venture at Leadhills. When Bishop Pococke visited in 1760 he commented that the workforce, (Pococke was not explicit in terms of precise mining occupation), were suffering from colic, which occasionally proved fatal, and that they had to resort to purgatives and emetics for relief.[62] Similarly Thomas Pennant during his travels in 1772 recorded that 'miners and smelters were subject to 'palsies and

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[58] Archibald Geikie , (ed.) *A Journey through England and Scotland to the Hebrides by B. Faujas De Saint Fond in 1784, revised edition of the English translation edited with notes by Sir Archibald Geikie Volume 2* (Glasgow, Hopkins 1901) p. 52.

[59] William Gilpin, *Observations, Relative chiefly to Picturesque Beauty, Made in the Year 1776 on several Parts of Great Britain, Particularly the High-Lands of Scotland, Volume 1 & II* (London: Blamire, 1789) Vol. I p. 174

[60] Parochial Board Minutes, Perthshire Reference XL2/3/1 1877-1894, Perth and Kinross Council Archive, AK Bell Library, York Place, Perth.

[61] Medical Officer of Health Journals, 1891-1929, Reference CC1/9/1-9 Perth and Kinross Council Archive, AK Bell Library, York Place, Perth.

[62] Daniel William Kemp (ed.) *Bishop Pococke's Tours in Scotland, 1747-1760* (Edinburgh: Edinburgh University Press, 1987) p. 42.

sometimes madness' from 'lead brash' (acute poisoning) that 'terminated in death'.[63] William Gilpin simply noted in 1776 that the mining was 'destructive of health' and the men were of 'infirm frame' with 'squalid looks'. [64] In 1842, the village doctor James Martin commented on 'paralyses of the muscles' particularly in the upper limbs, again it is unclear which class of worker was actually suffering. Martin also raised concern about the risk of poisoning that the juvenile males were exposed to when they were employed to clean the smelter flue.[65] Again paralysis is identified as the cause of death for three men and one of colic in Martin's 'Medico-statistical Report for 1841' which may indicate poisoning.[66] It was not just human health that was at risk but livestock too. A 'cow gang' was employed at the mine to keep animals away from both the dressing floors and areas polluted by 'effluent and fume'.[67]

It is tempting at this point in the study to argue that the relationship between production and pollution suggested in the landscape study may follow through into health and increased incidence of poisoning. At Leadhills an average of 2,000 tons of ore was raised per annum, which generated greater concentrations of lead in the environment which ranged between 21,200 mg per kg and 75,500 mg per kg.[68] Whereas at Tyndrum, even during Clifton's period of peak production, an average of only 424 tons was raised annually. Concomitantly, pollution values were much lower ranging from 43 mg per kg to 43,036 mg per kg.[69] An association between increased production and poisoning potentially follows also visible in the national context.

<u>Lead Poisoning in the National Context</u>

There are contemporary accounts of poisoning in the lead mines of England and Wales across all divisions of mine labour. In terms of the smelters, the Kinnaird Commissioners

[63] Cited in Smout, 'Lead Mining in Scotland' p. 127.

[64] Gilpin, *Observations,* Vol. II, p. 76.

[65] BPP *Children's Employment Commission*, p. 871.

[66] Ibid. pp. 871-2.

[67] William S. Harvey, 'Pollution at Leadhills: Responses to domestic and industrial pollution in a mining community', *Local Historian*, 24, 3 (1994) 130-8, 134.

[68] Rowan, *et al.,* 'Geomorphology and pollution': 57-65, 63. Also see John S. Rowan, and S. W. Franks, 'Heavy metal mining and flood plain response in the Upper Clyde Basin, Scotland', in *The Structure, Function and Management Implications of Fluvial Systems,* ed. F. J. Dyer, M. C. Thomas and J. M. Olley, International Association Hydrological Science, no. 276 (2002) pp. 143–50.

[69] Mills, Simpson and Adderley, 'The Lead Legacy', 47-72, 62.

commented on incidences of lead poisoning amongst the Yorkshire smelt workers, such as 'obstinate costiveness' that 'lasts for a week or ten days', in which 'death results if not relieved', and that 'repeated attacks result in paralysis'. [70] Doctor Peacock, fellow of the Royal Colleague of Physicians, senior physician at the Chest Hospital at Victoria Park and physician at St Thomas's who reported on behalf of the *Kinnaird Commission*, similarly noted 'colicky pains in the bowels' specifically amongst the men who cleared the flues at Nenthead and Eggleston in Teesdale.[71] Thomas Oliver who was influential in the regulation of occupational lead poisoning, suggested that alongside the smelters and workers who cleared the flues, those who broke up the slag with hammers for re-smelting were also equally at risk The process 'raised clouds of dust' into the air which the workers inhaled and or ingested if it settled on their food.[72]

There are also some scattered accounts of poisoning amongst the underground workforce in the wider context. Charles Thackrah, a pioneer in the field of occupational medicine, noted that a simple action such as the constant dashing of water in the face by the stroke of a pick axe resulted in poisoning, also the inhalation or swallowing of small rock particles suspended in mine air or simply absorbing the metal through direct contact with the skin. [73] Doctor William Webb writing in the *British Medical Journal* in 1857 noted poisoning amongst the Derbyshire lead miners and advocated butter washed down with a 'plentiful consumption of ale' as an antidote.[74] Doctor T. H. Jackson writing earlier in the same series described how the miners of Swaledale and Arkendale in the north Yorkshire moors absorbed lead through their skin, but he curiously denied any poisoning. Jackson did, however, raise health concerns about the men's working clothes harbouring lead particles, which were then transferred to the home. [75] Doctor William Ewart, mine surgeon employed

[70] BPP *Kinnaird Commission*, p. 142.

[71] BPP *Kinnaird Commission,* Appendix ' Diseases of Miners in the North of England and Wales, their family history, personal history and present state, p. 15.

[72] Oliver, *Lead Poisoning*, p. 5.

[73] Charles T. Thackrah*, The Effects of Arts, Trades and Professions and of Civic States and Habits of Living on Health and Longevity*, second enlarged edition (London, 1832), p. 93.

[74] William Webb, 'Diseases of Special Occupations No. V, *British Medical Journal,* No. XXXIII (August, 1857), 687-688.

[75] Thomas Hayes Jackson, 'Diseases of Special Occupations No. IV, The Miners of Swaledale and Arkendale', *British Medical Journal,* No. XXX (July 1857) 619-20.

by the London Lead Company, also raised a similar concern in that the flannel shirts that the miners wore to work were particularly absorbent and exacerbated the dust hazard.[76] Local physician Doctor Rumney, practicing in the early 1860s, in Patterdale, in what is now Cumbria, reported that he had observed what he termed 'lead paralysis' amongst the miners.[77] Similarly Peacock described, miners vomiting violently on return to the surface of the mine, complaining of headaches, weak limbs and that 'they suffered from pains in the bowls, constipation or diarrhoea…' [78] Of the twenty five miners from across the north of England and five from Wales that Peacock interviewed on behalf of the *Kinnaird Commission*, fifteen and three respectively described gastro-intestinal systems, such as intermittent constipation, anorexia and stomach pain, that potentially indicated poisoning.[79] Rosen in his classic study of *The History of Miners' Diseases* also suggested that it was 'probable' that the miners suffered a 'moderate degree of lead poisoning'.[80]

Reflecting the current literature, there are few references to poisoning specifically amongst the ore dressers despite their close proximity to a contaminated working environment both in terms of waste and water on potential daily basis. The *Children's Employment Commission* reported that inhaling and or ingesting small particles whilst the ore was broken with hand held hammers specifically in ore fields of north Wales resulted in 'constipation of the bowels and a peculiar kind of colic'.[81] This echoed the earlier concern voiced in the eighteenth century by the Welsh mine adventurer, Lewis Morris, that the ingestion or inhalation of minute particles of ore resulted in 'distemper'.[82] Contemporaries, however, clearly acknowledged that the dressing floor was a danger to livestock.[83] For example, in the Derbyshire Peak, dressing floors were often protected by stone walls known as a 'belland' or surrounded by trees to deter livestock from grazing on the contaminated

[76] BPP *Kinnaird Commission*, p. 382.

[77] BPP *Kinnaird Commission*, p. 327.

[78] BPP *Kinnaird Commission*, Appendix 'Diseases of Miners', p. 8.

[79] Ibid. pp. 82-93.

[80] Georg Rosen, *The History of Miners' Diseases, a Medical and Social Interpretation*, (New York: Schumans, 1943) p. 212.

[81] BPP *Children's Employment Commission,* p. 232 and p. 239.

[82] Cited in W. J. Lewis, *Lead Mining in Wales* (Cardiff: University of Wales Press, 1967) p. 283

[83] W. J. Lewis, *Lead Mining in Wales*, Cardiff: University of Wales Press, 1967) p. 283, and Arthur Raistrick and Bernard Jennings, *A History of Lead Mining in the Pennines* (Littleborough: George Kelsall, 1989) pp. 239-40.

land.[84] Lewis Morris described how '[D]ogs that frequent ye mines and lick up the dust with their meat are taken by fits and run about as if they were mad…' and '[T]o geese, ducks and hens it is fatal, and it is in vain to attempt to keep any near a [L]ead mine'.[85] Doctor Mitchell who also gave evidence before the *Children's Employment Commission* commented that at Alston Moor, 'no man allows himself or his cattle from many miles below a washing floor to take the poisonous draught' and some mining companies would simply buy up land adjacent to a mine to avoid the risk of being sued by their neighbours for polluting land and livestock. [86] Yet despite the environmental concerns surface, by the 1860s work at the surface of the mine was not perceived as 'injurious' to health.[87]

Recorded incidence of occupational plumbism in both in the Scottish and the wider national context appears to be of a fairly low incidence and confined to either the smelting process or specific mines and or regional ore fields; Leadhills, Derbyshire, Yorkshire and North Wales. All of these regions were major producers of lead at varying points in their respective histories ,[88] and this adds additional support to an association between production, pollution and ill-health.

<u>Cotemporary Understanding of Plumbism and Perceptions of Risk in the National Context</u>

There are however several factors that challenge this assumption. Individual mines are rarely named in the evidence and without reliable production data it is impossible quantify an association between major lead producers and incidence of poisoning in the wider context and any association may simply reflect the fact that contemporary observers, including the Children's Employment and Kinnaird Commissioners only visited the major mining regions. Whilst the low level and scattered incidence of poisoning cases in the national context may reflect a lack of observation and/or recording rather than an accurate reflection of morbidity, low incidence may also result from contemporary understanding of the condition and perceptions of risk.

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[84] Trevor D. Ford & Jim H. Rieuwerts (eds.) *Lead Mining in the Peak District*, fourth edition (Bakewell: Peak Park Joint planning Board, 2002) p. 78.

[85] Cited in Lewis, *Lead Mining in Wales*, p. 283.

[86] BPP *Children's Employment Commission*, p. 238.

[87] BPP *Kinnaird Commission*, Appendix 'Diseases of Miners', p. 8 and p.13.

[88] Burt, *British Lead Mining*, p. 98-99.

It is beyond the scope of the study to discuss the historical development of the recognition and understanding of lead poisoning and its relationship with occupation, but broadly up until the late eighteenth and early nineteenth centuries knowledge was fragmented and often inconsistent.[89] Some physicians working amongst the metal mining communities, such as Martin, Jackson, Rumney and Webb, were clearly familiar with the symptoms of occupational plumbism. Yet Peacock argued that the link between colic and the miners' work had not been proven and the symptoms were more likely to have resulted from either exposure to cold and damp conditions or working with their feet in cold water.[90] Chronic and particularly sub-clinical lead poisoning is hard to recognise even in present day and currently often only diagnosed on blood lead levels. Consequently, the condition may have simply become lost amongst the background noise of grumbling ill health and poor social conditions. Lead poisoning is also a great mimicker and many of the symptoms such as anorexia, headache, pallor and dizziness, were associated by many contemporaries with working in 'bad air'. This is the likely explanation for Peacock's failure to associate colic with lead poisoning. He was a chest physician and key focus of the Kinnaird Commissioners was establishing high mortality from respiratory diseases.

There was also a culture of blaming the sufferer which may have obscured the visibility of the condition even further, and victim blame is a common theme running through occupational health histories where good hygiene is required.[91] In terms of lead poisoning amongst mining labour, blame was linked with the deliberate practice of broiling meat on hot pigs of lead straight from the furnace and heavy alcohol consumption.[92] For example, at Leadhills an anonymous correspondent to the *Gentleman's Magazine* claimed that the health of the smelters had improved in response to a reduction in the quantities of alcohol that they consumed.[93] Although there was an element of accuracy in this

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[89] For a brief history of the disease see Guenter B. Risse, 'Mill Reek in Scotland: Construction and Management of Lead Poisoning' pp. 199-230 in Gunter B. Risse, New *Medical Challenges during the Scottish Enlightenment* (Amsterdam: Rodopi, 2005), also see Mushak, *Lead and Public Health*, pp. 403-4 and 729.

[90] BPP *Kinnaird Commission*, Appendix 'Diseases of Miners', p. 22.

[91] Thomas Oliver (ed) *Dangerous Trades: The Historical, Social and Legal Aspects of Industrial Occupations as Affecting Health by a Number of Experts* (London: Murray, 1902) p. 17.

[92] Cited in Risse, 'Mill Reek in Scotland', pp. 199-230.

[93] Cited in Harvey, 'Pollution at Leadhills', 133.

observation the association with heavy drinking was not widely recognised at the time. It was not until 1912 that Thomas Legge, the first Medical Inspector under the Factory Acts, described how alcohol exacerbates absorption of lead and only since the 1980s has a clear link has been firmly established.[94]

Moreover, incidence of poisoning particularly amongst the smelters was actually in decline.[95] Doctor George Whitley, a medical registrar at Guys Hospital, had investigated the health risks from working with both lead and mercury, reported that the increased efficiency of the smelting process had significantly reduced the risk of poisoning.[96] The introduction from the late eighteenth century of long horizontal flues that were often up to half a mile in length had reduced exposure to lead fume in the immediate vicinity of the hearth for both workforce and their cattle. Peacock, similarly noted that 'dropping of the hands' had entirely disappeared amongst smelters.[97] In the Alston mining districts increased ventilation at the smelt works been successful in reducing paralysis particularly of the upper limbs, although the workforce continued to suffer colic and constipation, and the practice of flushing the flues with a current water to remove fine particles similarly reduced suffering.[98]

In addition to reduced exposure, contemporaries did not expect poisoning to occur. The lead ore commonly mined in the UK is galena (lead sulphide) which is normally bound in a quartz-silica matrix. It is more biologically inert, or as McCord aptly described, 'reluctantly soluble' and is less well absorbed in the gastrointestinal tract compared to other lead compounds; it has low bio-availability.[99] This gave rise to the widespread belief that only the smelters, primarily due to the small particle size of the fume, were at risk of occupational plumbism.[100] The notion that miners and ore dressers were protected by the purity of the

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[94] Thomas M. Legge and Kenneth W. Goadby, *Lead Poisoning and Lead Absorption: The Symptoms Pathology and Prevention* (London: Edward Arnold, 1912), p. 37 and A. J. Shaper et al., 'Effects of Alcohol and Smoking on Blood Lead in Middle-aged British Men', *British Medical Journal*, 284, 30th January 1982, 299-304.

[95] Ibid. p. 402.

[96] Bartrip, *Home Office and the Dangerous Trades*, p. 64.

[97] BPP *Kinnaird Commission,* Appendix ' Diseases of Miners in the North of England and Wales, their family history, personal history and present state, p. 15.

[98] BPP Kinnaird Commission, appendix, Medical Report on the State of the miners in the Lead mining Districts of Alston, Nenthead, Allenheads and Weardale, 12.

[99] McCord, 'Lead and Lead Poisoning', 535.

[100] Mushak, *Lead and Public Health,* p. 409.

metal persisted in to the twentieth century.[101] Oliver, for example, noted in 1914 that the 'risk to health and life commences with smelting' when the impurities are driven off and into the atmosphere.[102] The only 'exemption' Oliver suggested, were miners who worked cerussite (lead carbonate or white lead) which is soluble and also friable; it readily breaks down into a fine powder. [103] Mining cerussite accounts for the high incidence of poisoning amongst the US western districts noted by McCord, Rickard and Hamilton, as opposed to the east where galena predominated. It also underlay the problems at Broken Hill in Australia, discussed in detail by Oliver in his lectures before the Royal Institute of Public Health published in 1914, where the men had to work through 200 feet of carbonate to reach galena.[104]

Notwithstanding the lack of production data, there are simply too many variables in operation to suggest that incidence of plumbism was directly related to the production of lead ore. Moreover two conflicting assumptions can be drawn from the limited contemporary understanding of the condition and perception of risk. On the one hand the reduced visibility of the disease explains the low level and scattered incidence of disease, on the other hand it could also suggest that the cases depicted in the historical record were indicative of a much wider problem. Whilst long flues clearly brought health benefits, the men increased their risk by consuming contaminated meat and drinking alcohol and in terms of the purity of the metal, Nriagu, has drawn attention to 'dirty' mines where lead compounds were mixed.[105] It was not uncommon for British lead miners to encounter pockets of lead carbonate whilst working galena, and some miners used the compound to tamp (pack) the explosive charge before firing. Moreover, galena as Nriagu comments 'is

[101] Mushak, *Lead and Public Health,* p. 33.

[102] Oliver, *Lead Poisoning*, p. 5.

[103] Ibid. p. 4.

[104] Ibid. White lead was used in paint and pottery glazes and these trades would eventually become the focus of contemporary concern and subsequent regulation from 1864. See Bartip, *Home Office and the Dangerous Trades,* chapters 3, pp. 81-100 and 4, pp 101-136.

[105] Nriagu, *Lead and Lead Poisoning*, p. 311.

not exactly non-toxic'.[106] It as this point in the discussion where the environmental record coupled with a case study approach reveals its value.

Contemporary Understanding of Plumbism and Perceptions of Risk at Tyndrum

Although current lead values are lower at Tyndrum than at Leadhills, compared to expected background levels they are still exceptionally high (see table two and three). Contamination was also likely to have been much greater during the operational phases of the mine. A moderate breeze (force 4 Beaufort scale) can carry lead particles of less than 2 centimetres some 1.8 meters distance and the lead pollution at Tyndrum is also moving via river sediment to Loch Tay some 25 kilometres east of the mine.[107] Moreover much of the waste that had accumulated on site was reworked between 1915 and 1922 and again from 1953 onwards to remove the remaining lead and also zinc, around 710 tons, classified as 'gravel', was also used in construction and road building.[108]

Notwithstanding the 'one off' occurrence of poisoning amongst the Tyndrum smelters in the seventeenth century, given the elevated levels of lead at the mine that the surface workers were theoretically exposed to, more cases ought to have occurred. A study in 1989 demonstrated that just living within a historic lead mining village results in elevated blood lead levels of around 45-70% compared with a non-industrial settlement.[109] Furthermore recent research published in 2009 suggested that blood lead levels as low as 10 micrograms per 100 millilitres of blood can result in cancer, hypertension and renal, neurological and reproductive damage. The Health and Safety Executive's recommended action level was at

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[106] Ibid.

[107] Angus B. MacKenzie and Ian D. Pulford, 'Investigation of contaminant metal dispersal from a disused mine site at Tyndrum, using concentration gradients and stable Pb isotope ratios', *Applied Geochemistry*, 17 (2002) 1093-1103.

[108] BPP HM Mines Inspectors Reports, Scottish Division, 1915-1922. A post card of the Royal Tyndrum Hotel published by James Valentine & co in 1953 depicts waste tips that are far more extensive than those remaining today (card no. 232241). Also see Pieda plc, 'Scottish Mineral Recycling', *Scottish Natural Heritage Review*, 36 (1995) 1-90.

[109] Wendy E. Moffat, 'Blood lead determinants of a population living in a former lead mining area in southern Scotland', *Environmental Geochemistry and Health*, 11, 1 (1989) 3-9, 8. Also see B. E. Davies, *et al.,* 'The relationship between heavy metals in garden soils and house dusts in an old lead mining area of north Wales, Great Britain', *Environmental Pollution*, 9 (1985) 255-266.

the time set at 50 micrograms of lead per 100 millilitres of blood for men and 20 micrograms for women.[110]

Table Two: Lead values at Tyndrum mine[111]

Site	Range Mg/Kg (dry soil)
Mine including 18th century dressing floor and 20th century crushing mill	52-60039
Glengary Crusher (19th century)	13-62713
Smelt Mill	19-9052

Table Three: Background lead contaminants in Scottish soils[112]

Soil material	Range Mg/kg
Mineral surface horizons	8.8-113
Organic surface horizons	1.9-245
Sub-soil	10-80

There are also two key extraneous factors that may have increased the risk of poisoning amongst the Tyndrum workforce. Labour employed at the dressing floor particularly in the nineteenth century was predominantly juvenile and consequently more susceptible to absorption of the metal through the gut. Heavy alcohol consumption at the mine was also problematic. James Stirling had to remove farming tenants who regularly supplied the miners with drink, yet he would use alcohol when it suited to resolve industrial disputes.[113] In the nineteenth century the company store keeper, James Crerar, who was

110 'Dangerous Lead', *Hazards Magazine*, Special Report, November 2009.

111 Data sourced from Mills, Simpson and Adderley, 'The Lead Legacy', 47-72, Table 2 and 2A, 58-9, Table 3, 63 and Table 4, 66.

112 Ed Patterson, Willie Towers, J. R. Bacon and M. Jones, *Background Contaminants in Scottish Soils* (Aberdeen: Macaulay Institute, 2002) p. 50.

113 Moreton, 'Lead mines of Tyndrum', 41-2.

also described as ‘addicted to drink’, frequently allowed the men whisky from the store irrespective of either their ability to pay or their mounting debts.[114]

Although it is impossible to rule out bias in recording and/or lack of recognition and understanding of the disease, Risse has highlighted the role of Edinburgh academics in promoting a greater understanding of lead poisoning in the 1790s. This, he suggested, was prompted by physician and chemist Joseph Black’s visit to Leadhills mine and his relationship with the Earl of Hopetoun who owned the mineral rights.[115] Leadhills and Tyndrum mine were both operated by the SMC and both were managed by James Stirling. The Company employed James Martin as a mine surgeon to specifically attend the men. Martin was an ex-military surgeon who had considerable experience in the Peninsula Wars and the West Indies and was familiar with plumbism from the lead rum stills.[116] As discussed above he had previously expressed concern before the *Children’s Employment Commission*. Although he did not practice at Tyndrum, it is likely that Stirling would have had some awareness of the condition particularly given the problems at Leadhills. The Company under Stirling had responded by introducing long flues in 1806 and relocating the smelter away from the village.[117] The local general practitioner doctor Wilson had advised that the men take regular purgatives and avoid breathing contaminated air to avoid lead colic.[118] The miner’s library also contained contemporary volumes on health,[119] and the company operated, albeit rather limited, paternalistic welfare policies at both mines.[120]

In contrast to Leadhills, improvements in smelter technology were not introduced at Tyndrum during the SMC’s lease. The Company operated a ‘Scotch furnace’, which was essentially a hearth and a short chimney which discharged an estimated 60% of lead directly

[114] NRS GD112/18/9/5/23.

[115] Risse, ‘Mill Reek in Scotland’, pp. 212-219.

[116] Harvey, ‘Pollution at Leadhills’, 31.

[117] Risse, ‘Mill Reek in Scotland’, pp. 20 and 11.

[118] Harvey, ‘Pollution at Leadhills’, 133.

[119] Risse, ‘Mill Reek in Scotland’ p. 20

[120] Ibid., Risse, Harvey, ‘Pollution at Leadhills’, 3. For brief discussion of ‘welfare’ measures see Catherine Mills, ‘Technological Innovation and Adaption: Tyndrum Lead Mines and the German Managers, 1838-1865’, 115-126, 123 and 125 in D. J. Linton (ed) Mining Technology: Technological Innovation in the Extractive Industries, *Welsh Mines and Mining*, 4 (2015).

to the atmosphere during efficiency trials.[121] By the nineteenth century phase of operation the smelter had fallen out of use. The workforce also came under greater scrutiny during this period as the German mine managers perceived their safety and well-being as a company responsibility. All three Germans (see table one above) focused on improving wider social conditions, such as housing and the diet of the workforce. Thost in particular, introduced measures to reduce alcohol consumption and encouraged debt reduction and he attempted to promote improved health and safety conditions at the mine, such as the provision of mechanical ventilation and the prohibition of hemp ropes which were prone to breakage. [122] Although all these measures were primarily driven by economic motivations such as increased productivity of the workforce, it is unlikely that poisoning or other debilitating diseases would have gone unnoticed.

Neither were the Tyndrum workforce protected by the purity of the metallic ore as suggested by Oliver. A recent environmental survey of the site by the Macaulay Institute in 2008 at the request of the current land owners the Forestry Commission for Scotland recorded levels of lead and other potential toxic elements (PTEs) and the bioavailable fraction of metal contained within the soil at the site.[123] The study revealed the presence of lead carbonate and leadhilite together with lead sulphide. Tyndrum was a 'dirty mine'. Of the twelve samples taken across the site, three posed risk to infants (under 5years) and one posed risk to an 'average person' as measured against a Hazard Index score. The study concluded that the current risk of exposure was 'minor and would only develop into chronic health problems where individuals were experiencing repeated exposure'.[124] Whilst this has resulted in recent fencing at the site to protect the public it would have posed a significant risk to the workforce if they were exposed to the waste on a daily basis across long periods.

The Macaulay study focused on the twentieth century mill site, consequently an additional analysis of bioavailability at the nineteenth century mill and dressing floor at Glengary and at comparable sites at Leadhills that were operational in the roughly same period, was undertaken by the authors in 2013. These analyses reveal that the bioavailable

[121] NAS GD112/18/4/1/61

[122] NRS GD/18/4/1/65, NRS GD112/18/4/1/65, NRS GD112/18/8/16/19 & 20 and NRS GD112/18/9/5/10

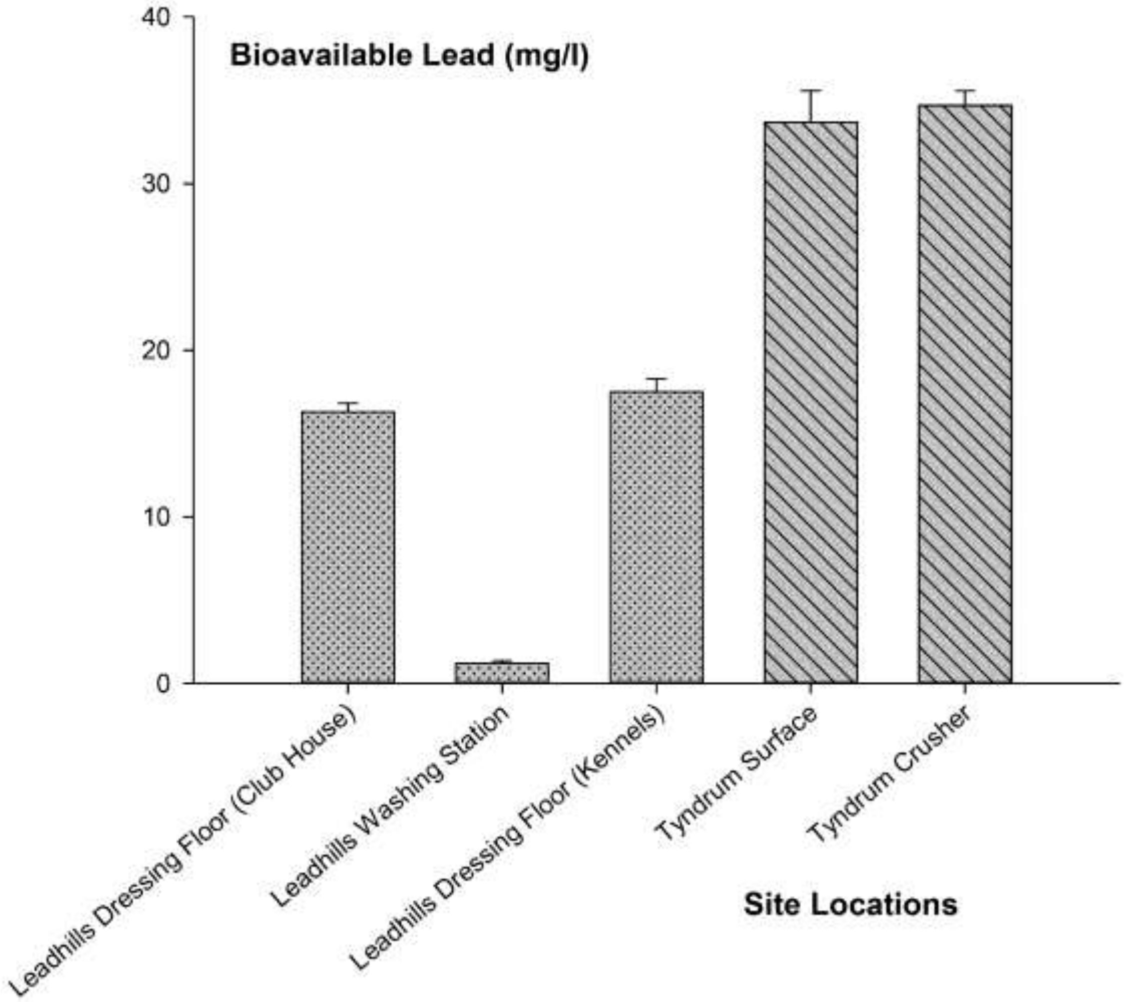
[123] A. J. Noland, S. Hillier and R. Hough, Sampling and Analysis of Lead Mine Spoil, Tyndrum, Argyll, and its Implications in Relation to the Expansion of Visitor Access: A Report for the Forestry Commission Scotland, (2008).

[124] Ibid p. 14.

lead extracted from sediment samples showed significantly greater quantities in the Tyndrum context (see figure 1 below).[125] Examining the nature of the lead materials in each sample further reveals that materials from Leadhills were different to Tyndrum and that they are more readily dissolved in stomach acids. Such differences can be attributed to the proportions of different lead compounds found at each site. These results suggest that for the same exposure to the crusher sediments the degree of poisoning would greater amongst the Tyndrum workforce, and at Leadhills the exposure was less than that seen at Tyndrum but the lead due to its ability to readily dissolve was essentially more toxic. These results may explain the greater incidence of occupational poisoning at Leadhills, but again do not explain the absence of occupational plumbism recorded at Tyndrum and indicates that the workforce specifically at this location and also perhaps more widely in the national context were either protected in some fashion or minimally exposed.

Figure 1. Bioavailable lead concentrations for a set of sites at Leadhills and at Tyndrum, Scotland. Mean of three replicate analyses (bar) and standard deviation (T) shown. Assay conducted using *in vitro* analyses to mimic stomach acids.

[125] United States Environmental Protection Agency, Standard Operating Procedure for an *In vitro* Bio-accessibility Assay for Lead in Soil, EPA9200.1-86 (November 2008), 1-10.



<u>Protective Factors</u>

In the wider British context there was no statutory health and safety protection, surface work in the metal mining industries was regulated under the Factory Acts from 1864 but this was not enforced until the introduction of the Metalliferous Metal Mines Regulation Act in 1872. [126] Whilst there were no formalised hygiene safeguards to protect the workforce, indirect influences, broadly categorised as material, specifically diet, and climate, socio-economic factors, such as a dual occupation and lastly technological advances as mining industrialised, all operated to counteract against occupational plumbism.

[126] Mills, *Regulating Health and Safety*, p. 153

A diet rich in nutrients such as Vitamins C, D and E alongside selenium, zinc, iron, magnesium, chromium and amino acids, Davies and Stewart suggest, help to reduce the metabolic effects of lead, [127] Diet varied across the different mining regions. In the northern districts it was largely based on potatoes, barley and oats with the addition of milk and cheese. The Derbyshire miners in particular, consumed large quantities of bacon and other meat fat based on the local believe promoted by William Webb that it protected against poisoning.[128] Climate also played a key role in protecting the workforce against poisoning by reducing the length of time that they were exposed to potential contamination. Most lead mines were located in remote upland regions such as the Derbyshire Peak, the Yorkshires Dales, Mid and North Wales, the Mendips, Cumbria, Northumberland, County Durham and North Yorkshires Dales.[129] Whilst mining was wholly reliant on water power continuous operation was subject to vagaries of the weather. Heavy snowfall and freezing temperatures in winter, floods in spring and autumn and drought in summer all halted surface work and enforced a seasonal pattern of operation.

This 'on-off' practice of working was additionally reinforced by socio-economic factors. Mining labour also farmed, essentially they held duel occupations As Burt points out most miners and their families produced their own basic food requirements, combined mining with either a small-holding or hill-farming and took several months off each year for harvesting and haymaking.[130] The weather and farming combined significantly reduced the amount of time the workforce were exposed to their hostile working environment, and the periods spent away from the mine would have allowed time for the body to recuperate and repair.

Excepting small scale ventures, by the 1840s mining had largely taken precedence over farming.[131] This was in response to increased demand for raw materials, the application of steam power to pumping and winding and the shift towards regular and more disciplined work patterns that had begun in the late eighteenth century. Although

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[127] Stephen Davies and Alan Stewart, *Nutritional Medicine, (London: Pan, 1987)* p. 96. Also see A. Roberts, 'Food, Nutrition and Lead Absorption', LEAD Action News, 10, 2, (2010)1-41.

[128] Burt, *British Lead Mining*, p. 175. See note 74 above for specific reference to William Webb.

[129] Burt, *British Lead Mining*, pp. 1-2

[130] Ibid. p. 167.

[131]Ibid. p. 168.

industrialisation increased worker contact with a lead laden environment, for the underground workforce the most visible bodily damage was in their respiratory health with an associated decline in mortality. This overshadowed all other occupational health concerns and as discussed above the similarity of some of the symptoms of respiratory disease, such as pallor, may have further masked cases of poisoning. On the other hand, mechanisation at the dressing floor actually reduced the number of workers employed and concomitantly the numbers at risk. For example at Snailbeach lead mine in Shropshire labour costs fell from 16/- to 6/- 6d per ton and also significantly reduced the amount of residual ore in the waste further reducing the risk of exposure. [132] By the opening decades of the twentieth century, lead poisoning according to Divisional Mines Inspector for Scotland, Mr. William Walker who had previously served in the Durham and North Riding of Yorkshire and Westmorland Inspection Districts, had ceased to be a problem.[133]

Although nutritional protection against lead absorption is largely unproven, a reduction in exposure to the contaminated working environment through climate, socio-economic and technological advances minimise the risk of poisoning and suggests that the low incidence was accurately recorded in the historical record. Protective factors were also in operation at Tyndrum. Although the German managers had paid attention to the welfare of the workforce, there were no voluntary provisions at the mine to reduce exposure to lead, such as changing rooms for the removal of contaminated work clothing, washing facilities or a separate space to consume food. The workforce were however protected indirectly by similar material and socio-economic factors. In terms of diet, Easson has drawn attention to the Tyndrum miners' diet of kale, berries, potatoes, turnips, dairy and meal, all rich in the protective nutrients.[134] Equally they were dogged by the British weather. For example, in 1781 during a total of 30 weeks smelting there were seven 'weather' interruptions of over seven days duration.[135] The winters of 1782, 1784 to 1786 and 1791 also halted all smelting, and the summer drought of 1785 was so severe boats were unable to get into harbour at the head of Loch Lomond to transport materials in and out of the

[132] Burt, *British Ore Preparation Techniques*, p. 60.

[133] Cited in Mayers, *Balmaidens,* p. 141

[134] Easson, 'Environmental Degradation', pp. 79-80

[135] Table 6 SMC Bar Lead Output 1770-1790, in Easson, 'Environmental Degradation', p. 74

site.[136] During one summer drought Thost, employed the entire surface workforce on repairing a dam and lade, originally constructed by the SMC to the west of the site, to both help solve water shortages and ensure that the surface workers had a wage whilst the mine was out of operation.[137] In the nineteenth century the records are littered with comments such as 'dressing suspended due to bad weather', 'hampered by the weather' and 'frost retarded dressing'.[138] The seasonal pattern of operation acting as a protective influence are well illustrated by the circumstances surrounding the isolated poisoning incident amongst the Tyndrum smelters in 1784. This period of ill-health resulted from nine weeks of intense activity in which 394 bars of lead were produced. What was unusual about this period was that it was continuous and defied the usual irregular and seasonal pattern of operation.[139]

It was not just the weather that thwarted activity but poor maintenance too. By 1860 the crushing mill at Glengary required constant repair and replacement of the rollers, and was frequently out of action leaving surface labour idle.[140] The men also farmed. The remaining landscape features of the miners' cottages at Tyndrum suggest a kitchen garden and the workforce were also allowed potato ground and grassland for their cattle.[141] By the nineteenth century the men were also keeping pigs.[142] In addition turnips and corn were also raised,[143] and at least two months of every year was spent cutting hay and peat. [144] The duel occupation persisted up until the closure of the venture in early 1860s and the men's health continued to benefit from a seasonal pattern of working. The mine did not industrialise until the Tyndrum Lead and Zinc Company's leased the mineral rights in 1916 (see table one).

[136] SMC DK.7.28/5, DK7.28/3 and GD112/18/8/2/20

[137] NRS GD112/18/8/15/4

[138] NRS GD112//18/8/14/32, GD112//18/8/16/22 and GD112/18/15/2

[139] Easson, 'Table 6: Scots Mining Company Bar Lead Output 1770-1790' Environmental Degradation, p. 74.

[140] NRS GD11218/8/15/30.

[141] Moreton, 'Lead Mines of Tyndrum', p, 58.

[142] NRS GD112/18/9/5/24.

[143] *New Statistical Account* of *Scotland,* 1834-45, Volume 10, Killin, County of Perth p. 1078.

[144] Easson, 'Environmental Degradation, p. 75, Moreton, Lead Mines of Tyndrum', 58 and for specific incidences see, for example, GD112/18/8/14/25, GD112/18/8/15/15.

A reduction in exposure to the contaminated working environment resulting from climate and socio-economic influences can explain the general absence of poisoning at Tyndrum, the environmental legacy at the mine compared with Leadhills, however, challenges this assumption. The Leadhills workforce should have been protected to some extent by similar factors. The mine was located on high bleak moorland between 375 and 475m and similarly struggled with the capricious and often harsh nature of the British weather.[145] The Leadhills workforce also farmed in a comparable part-time fashion to the Tyndrum men with a 'kitchen garden', a plot of land around three acres, they also kept sheep and cattle and would have probably consumed a similar diet. [146] Yet they suffered poisoning, whereas the Tyndrum men despite being exposed to lead that was more available did not. This prompted the question why and prompted further scrutiny resulting in a more nuanced and deeper understanding of the 'on-off' pattern of operation.

The ore deposits at Leadhills were more extensive and much more economically viable than at Tyndrum. Excepting lawsuits over water rights in the 1840s and 1850s, the mining venture witnessed successful and continuous operation across its history. In addition the mineral owner, the Earls of Hopetoun were concerned with the long term development and maintenance of the mine, as discussed above the smelting process was improved and steam power was also harnessed from the early 1800s. [147] This resulted in the workforce being exposed to less available lead but for a much longer and consistent period. Whereas operations at Tyndrum were speculative resulting in continual changes in leaseholders who gambled on making a profit interspersed by lengthy periods of abandonment amounting to 85 years of its 198 year history (see table one). Whilst this reduced long term exposure to lead, the short term seasonal pattern of working was, particularly in the 19th century, also taken to the extreme, mining activity at Tyndrum was essentially a pretence. It is likely that these factors explain the absence of poisoning despite the high levels of available lead.

At the end of the eighteenth century when the viable ore was exhausted at Tyndrum the SMC had astutely pulled out of operations and concentrated their activities at Leadhills.

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[145] Harvey, 'Pollution at Leadhills', 130.

[146] W. S. Harvey, 'Miners or Crofters?', *British Mining,* 43 (1991)82- 95, 84 and 88.

[147] For a detailed history of the mine see W. S. Harvey, Lead and Labour: A Social History, 1999, unpublished manuscript, unpagainated, National Library of Scotland, Edinburgh HP4.203.0481.

The second marquis, as discussed above, took a gamble on re-opening Tyndrum despite its limited potential. [148] The venture, was as manager Sigmund Reichendorf, described, no different to the marquis's 'emu, and deer and pheasants and a museum and other remarkable things for your pleasure, not for any use'.[149] It was essentially a show mine. In addition to the stoppages at the mine for bad weather, poor maintenance and farming duties, the men although employed, rarely fulfilled their bargains. There was no incentive for them to labour as they were given credit at the company store and tenancies on their houses irrespective of their debts or ability to pay. The men were described as 'lazy', as 'perfect invalids' and were frequently too drunk to labour. Industrial relations were poor and when the miners were at work they would often down tools.[150] This all had a knock on effect on surface labour who often had no work because they had simply run out of ore to process.[151] Although Reichendorf's perception of the mine may have been clouded by his poor relationship with the marquis and the Tyndrum workforce. Harrison who replaced him similarly grumbled about the workforce.[152] Renowned mining engineer, George Henwood, writing in the *Mining Journal* in 1860 commented that the mine merely provided employment for the poor tenants of the estate.[153] This is aptly illustrated by the frequent removal of the entire workforce from the mine to work on the construction of marquis's canal venture at the head of Loch Lomond. [154]

It is impossible to assess the extent to which the very specific circumstances at Tyndrum mine mirror the wider context without much more focused research. Burt notes that partnerships of miners would combine to defraud mineral owners, alongside theft which was 'as old and widespread as mining'.[155] It was also not uncommon for miners to disguise good quality ore for example blackening it with candle smoke in an attempt to

[148] Moreton, 'Lead Mines of Tyndrum', 57-95.

[149] NRSGD112/ 18/9/5/25.

[150] NRS GD112/18/9/5/17.

[151] NRS GD112/18/9/5/13.

[152] NRS GD112/18/9/6/10/13.

[153] George Henwood, 'Mining in Scotland and the Tyndrum Mine' *Mining Journal,* 1860, 715 and 724.

[154] NRS GD112/18/9/5/23.

[155] Burt, *British Lead Mining*, p. 146-7.

negotiate more favourable terms.[156] At Tyndrum mine, however it was more complex than straightforward fraud and theft, in that the men took credit at the company store but were rarely at work and consequently their exposure to the hazardous working environment was limited. They were, however, not without risk of environmental exposure, their cottages were located at Clifton (now subsumed into Tyndrum) at the foot of Minehill roughly 1.5 kilometres downwind of the mine and would have been exposed to windblown pollution particularly during the dry summers. Moreover, up until the early twentieth century the settlement also shared its water supply with the mine.[157] Given the current lead values and the availability of the compounds revealed in the environmental record, coupled with results of the recent studies by Moffat and Davies et al, it is unlikely that the workforce would have wholly escaped contact and were probably chronically poisoned albeit at a sub-clinical level.[158]

Conclusion

Occupational plumbism in the eighteenth and nineteenth centuries occurred across all classes of mine labour, smelters, ore dressers and miners. Incidence was scattered and at fairly low level. The high environmental lead values at Tyndrum mine suggest significant exposure amongst the workforce and potentially amongst lead mining labour in the wider national context. Medical knowledge of the condition was limited and the recognition of the condition was riddled with misconceptions, not least the belief that the purity of the metallic ore offered protection from absorption and this directed attention to the hazards of smelter fume. This resulted in engineering solutions spurred on by an additional need to reduce the hazards to adjacent pasture and grazing livestock. These measures that included the introduction of long flues and improved ventilation were largely successful in reducing incidence of plumbism amongst the smelters but served to diminish the visibility of risk amongst miners and the labour force employed at the dressing floor.

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[156] A. K. Hamilton Jenkin, *The Cornish Miner* (Newton Abbot: David and Charles, 1972) p. 229.

[157] Journal of the Medical Officer of Health for Perthshire, 1891-2, entry 15/06/91, CC1/9/1/1, Perth and Kinross Council Archive, AK Bell Library, Perth.

[158] See note 109 above.

The relationship between production and pollution does not follow strongly through into health and incidence of occupational plumbism correlates more persuasively with the length of time the workforce were exposed to the contaminated environment. The hazards of working with lead ore were moderated by diet but primarily by the seasonal nature of operation in the pre-industrial phase of mining and the adoption of a duel occupation. This minimised contact with the metallic ore, particularly the more available compounds such as lead carbonate. It also allowed the body periods of recuperation. At Tyndrum mine in the nineteenth century an intermittent pattern of working was taken to the extreme and appears to be unique. The men were rarely at work and consequently their exposure to the hostile working environment was minimised further.

Although Tyndrum mine did not introduce steam power and regular working hours as mining industrialised, in the wider context this heralded new and more pressing occupational health problems in the form of respiratory disease for the miners whilst simultaneously reducing the number of surface workers exposed to the heavy metal. By the opening decade of the twentieth century the documentary evidence suggests that occupational poisoning amongst mining labour had ceased to be a problem. At Tyndrum mine even during periods of abandonment given the elevated lead concentrations and the bio-availability of the compounds revealed in the environmental record coupled with a shared water supply and the close proximity of their homes and small holdings to the mine it is unlikely that their risk was wholly zero.

The adoption of an integrated approach that combined traditional documentary evidence with the environmental record facilitated a deeper more resonant history. Lead, although it is moved by wind and water, does not degrade and consequently the current legacy opens a wide window onto the historic working environment and the high levels of contamination to which the workforce were potentially exposed to. This shaped and directed the original research questions and subsequently initiated the exploration of protective factors given the discovery of a low incidence of occupational plumbism amongst the workforce. It also helped plug the gap in the absence of mortality and morbidity data and prompted a deeper scrutiny of the documentary record that has increased qualitative knowledge and understanding of the historic risk of occupational exposure to lead.

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