

Technological Innovation and Adaption: Tyndrum Lead Mine and the German Managers, 1838 to 1865

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Abstract: In 1838 the second Marquis of Breadalbane, having failed to lease the mineral rights at Tyndrum lead mine on the Campbell family estate in the southern Scottish highlands, made a decision to work the mine himself. When he began his operation, the mine was nearing exhaustion and what little productivity remained was hindered by increasingly complex mineralisation. The Marquis, however, was convinced that the mine could still produce great wealth; he looked to Germany for expertise and employed a succession of German mining engineers to manage his ailing operation. The survival of their monthly progress reports and other documentation offers a unique perspective on the Scottish lead mining industry and the adaptive strategies, in terms of technological innovation and mining practices, that the Germans employed to prolong the venture's economic survival.

Introduction

It was Jacob Schmookler who first drew attention to the distinction between an invention and a sub invention when exploring the process of technological change. Sub invention, he argued, was an 'obvious change in a product or process' resulting from the application of engineering knowledge and/or acts of skill, and this included the notion of 'routine innovation', previously described by Merrill as a modification that a 'skilled practitioner' would be expected to make in a product or process to adapt it to suit minor changes (Schmookler 1966, 6). Burt described these processes in the early 1990s, specifically in relation to non-ferrous mining, as the 'straightforward application of engineering knowledge and or acts of skill by the workforce', and he used the idea, in part, to challenge the traditional view that the Germans established world leadership in the mining and metallurgical arts and subsequently brought their knowledge to Britain (Burt 1991, 251–254).

Rather than engaging with the question of who pioneered British non-ferrous metal mining (the focus on German engineers in this instance is purely coincidental), this study examines the process of sub invention or routine innovation as a strategy for economic survival at Tyndrum lead mine in the mid nineteenth century. Whilst the application of key inventions to rock removal, blasting, haulage and pumping ushered in the era of deep mining, it was often small adjustments and modifications to existing equipment and infrastructure that enabled mining companies to gain further economies in extraction. The fickle nature of lead ore deposits and a volatile mining market created a dynamic industry responsive to change and well versed in technological adaptations to either produce more for less money, or work associated minerals that could be raised and marketed at a profit. The story of Tyndrum is not a new one, but the abundance of surviving documentary evidence opens a wider window onto both the process of adaptive strategies and sub invention at a mining operation nearing the end of financially viable extraction and processing; and it captures the futility of economic resilience in working a finite resource.

Although Scotland was not a major contributor to the

total national output, lead ore was mined in the majority of the Scottish shires (Wilson 1921, 2); yet research on the industry located north of the border compared to that in England and Wales has been sparse. Burt, in his study of the British lead mining industry, only makes fleeting references to Scotland (Burt 1984). Smout offers a single but detailed chapter on the economic context, and Harvey has explored aspects of the social history of the ventures at Leadhills and Wanlockhead in the Southern Uplands (Smout 1967, 103–135; Harvey 1972, 1991, 1994a, 1994b, 1999). Callender and Macaulay have focused on the metal mines of Islay (Callender & Macaulay 1984). More recently Callender, together with Reeson, has examined the Scottish gold rush at Kildonan in the 1860s, largely from an archaeological perspective (Callender & Reeson 2007). There are also several short studies on the mines of the Ochils, Tomnadashan on south Loch Tayside, and Galloway (Bainbridge 1980; Dickie & Forster 1974; Devéria 2001; Cressey *et al.* 2004; Moreton 2008). The mine site at Tyndrum has primarily attracted the interest of environmental and geo-scientists (MacKenzie & Pulford 2002; Farmer *et al.* 1997). More recently Mills, Simpson and Adderley have attempted to link current pollution levels at the site to historic mining practices (Mills *et al.* 2014). This study expands both the burgeoning Scottish narrative and the specific history of mining at Tyndrum from a technological perspective.

Tyndrum lead mine and the second Marquis of Breadalbane

The mine is located in the Loch Lomond and Trossachs National Park at the western fringes of Tyndrum (see Fig. 1), in the north-west of the historic Campbell family estate of Breadalbane in the southern Scottish highlands. It is situated south of the A82 Glasgow to Fort William road on the northern flanks of Sròn nan Colan, commonly known as Minehill. The mine was one of Scotland's largest producers of ore after Leadhills (Smout), and has a two hundred year documented history of intermittent operation (see Table 1). The lease of the mineral rights in the early eighteenth century was part of wider commercialisation of the estate following the Act of Union in 1707 (MacInnes 1998, 177–201,

Table 1 Timeline: Tyndrum mine

Year	Lease holder	Production annual average (tons)
1730	Sir Robert Clifton	424
1745	English Company of Mine Adventurers	136
1760	Rippon Company	165
1762	Paton and Richardson	157
1768	Scots Mining Company	153
1791	abandonment	0
1838	second Marquis of Breadalbane	25
1865	abandonment	0
	Tyndrum Mining Company	0
1916	Tyndrum Lead and Zinc Company	27.5
1928	abandonment	0

191). Although there is some indication that the lead had been worked in the vicinity of Tyndrum in the fifteenth century (OSA 1791–99, Parish of Glenurchy and Inishail, 35), it is Sir Robert Clifton who is credited with the discovery of the ore in 1735.

In the eighteenth and nineteenth centuries the remote and isolated location of the mine (Fig. 1) hindered the transportation of both lead (ore and bar) to market and coal (for fuel)



Fig. 1 Tyndrum location

and materials into the site. The route involved carriage by packhorse to the head of Loch Lomond, a distance of around 18 kilometres, and then by boat to the river Clyde. Not only was this expensive, but in the late 1830s it took five weeks from purchase to get material delivered from Glasgow (NRS, GD112/18/8/7/14). The final company to work the mineral lease, the Tyndrum Lead and Zinc Company (see Table 1), was the only venture to be able to take advantage of the Callender to Oban Railway for transportation, which reached Tyndrum in 1873, but by then the quality and quantity of the ore had dwindled and the company primarily re-worked the dumps. As a consequence the mine was heavily reliant on water power and the vagaries of the weather for most of its history. The water supply was either frozen in winter or in flood or dry during the remaining months. This, coupled with miners' need to cut peat for fuel, both for the mine and domestic use, together with hay for winter fodder, produced a marked seasonal pattern of working. The site of the mine also posed difficulties (Fig. 2). It was at high altitude, the entrance to the upper workings being at 500 metres above sea level, and Minehill was steep sided, averaging an incline of around 1 in 4. Mine labour was housed in cottages on the western fringe of the village of Tyndrum. These were built in the 1730s under the terms of Clifton's original lease. The miners were largely inexperienced and recruited locally from within the Breadalbane estate.

This study focuses on the period 1838 to 1865 when the landowner, John Campbell, the second Marquis of Breadalbane, essentially worked his own mineral lease primarily under the management of German engineers. The Marquis took an interest in science and technology and was a keen amateur geologist (Easson 2011, 63). He frequently roamed the hills between Taymouth Castle and Tyndrum in the company of his dogs, searching for minerals with a leather bag and a geologist's hammer (Gillies 1980, 212). His personal collection of minerals was exhibited at Crystal Palace in 1851. The Marquis also believed somewhat erroneously that the estate would produce great mineral wealth (Robertson 1992, 189–217, 192). Aside from Tyndrum mine, mineral deposits had been located at Lochearnhead and immediately south of Loch Tay at Corrie Buie, Ardtalnaig, and Tomnadashan, which was worked for copper pyrites. There were sufficient small-scale discoveries throughout the adult life of the Marquis to reinforce his belief that the Breadalbane estate would eventually yield rich deposits; examples of such discoveries were a small nugget of gold at Lochearnhead in 1855 and the small silver yield at Tyndrum (NRS, GD112/18/8/16/1; also see Table 2 below).

In spite of a nationwide advertising campaign in the early nineteenth century the Marquis failed to attract any interest in the mineral rights to the estate (NRS, GD112/18/9/8/33), and in 1838 he decided to work the lease himself. The Marquis employed George Baron to manage what was essentially an ailing venture at Tyndrum. Baron had previously worked at the Strontian lead mines and brought with him experienced miners (NRS, GD112/18/8/7/2).

The landowner employing a salaried manager, with varying degrees of autonomy, appears typical of the Scottish metal mining sector. For example, John Erskine primarily directed his silver mining venture at Alva, in Clackmannanshire, leaving his wife Catherine in charge



Fig. 2 Tyndrum mine today: the upper workings of Tyndrum showing the open cut and the remains of two dressing shelters constructed during Clifton's original lease (to left of centre)

of operations whilst he was raising guns and gold for the Jacobite cause and later in exile (Moreton 2008). In the case of Tyndrum, the Marquis vigorously directed his managers, either himself – when he was resident at Taymouth Castle at Kenmore, some 57 kilometres from Tyndrum – or via his factor, John Wyllie, whilst he was resident in London.

The Marquis demanded a detailed monthly account of his managers' activities, and in turn they requested weekly reports from the overseers, who primarily managed the Marquis' peripheral ventures. These reports together with correspondence and other documentation, such as the factor's business notes and records of the miners' bargains, have all survived and are archived at the National Records of Scotland in Edinburgh (NRS, Breadalbane Muniments, GS112/). Unfortunately the archive contains few copy letters from the Marquis and, whilst the mine managers recorded expenses, full financial details are sporadic. Nonetheless the surviving documentation, together with substantial archaeological surface remains at the site, opens a window onto Scottish metal mining history, the daily operation of the mine, social conditions, labour relations and, specifically in relation to this study, mining practice and technology.

Whilst the Marquis employed the German mining engineers specifically for their expertise, he would only heed their advice if it suited him. For example, he would often send the same mineral sample for assay several times until he got the results he wanted and between 1837 and 1856

he spent £42,457 primarily on the assaying of minerals from his estate, trials, independent surveys and continued exploratory work at Tyndrum (NRS, GD112/18/1/8/4). He eventually had a laboratory installed at Taymouth Castle to assay minerals himself (NRS, GD112/18/9/5/7). The Marquis would also interfere, either directly or via John Wyllie, with the management of the workforce. For example, Wyllie determined which tenants were employed at the mine, and the Marquis himself cut the pay of miner John Forbes for requesting a pay rise (NRS, GD112/18/9/8/37–8). The records suggest that the Marquis was not an easy man to work for.

Aside from the innate difficulties of a remote location, when the Marquis began his operation, the workings at Tyndrum had been abandoned for over thirty years and the mine was nearing exhaustion. The increasing complexity of the mineralisation made it difficult to extract the lead ore from the country rock and associated gangue ores. In particular zinc, galena and blende occurred in equal proportions, and occurred as small single crystals dispersed in quartz (Wilson 1921, 95). In addition, as Odernheimer, the first German to arrive at Tyndrum, described, the quartz was 'too hard and the ore too soft' to separate efficiently (NRS, GD112//18/8/7/25). The Scots Mining Company had astutely pulled out at the end of the eighteenth century when their lease had expired.

The Marquis began his venture by replacing the surface infrastructure at Tyndrum without first having proven the

ground. He had a water powered crushing mill with adjacent sheds for bruising and washing the ore constructed at Glengarry some 1.5 kilometres east of the mine site, together with a stone lined leat to supply water from the Crom Allt, taken from just east of the mine site. He also had a new waggon way laid from the base of Minehill to Glengarry linked to the main levels at the mine site via an inclined plane (NRS, GD112/18/8/7/2). There were no arrangements for primary separation of the lead ore from waste rock or gangue metals at the mine. If the rock was of mixed mineral content it was either dumped *in situ* at the surface of the mine or carried by the waggon way to Glengarry. Plans were also drawn up to erect a smelter adjacent to the crusher. Baron certainly implied that the walls were subsequently constructed by stating that the roof would be prepared as soon as the chimney was built (NRS, GD112/18/8/7/2). In the interim ore was sent for smelting to Alloa in Clackmannanshire and also to north Wales, but primarily to Glasgow (NRS, GD112/18/8/1/6 and 10). Previously both Clifton and the Scots Mining Company had dressed their ore on Minehill and smelted around 3 kilometres downstream from the mine at the confluence of the Crom Allt and the river Cononish at Dalrigh (see Fig. 3). The ambition of the Marquis' plans is indicated by the proposals to construct a canal linking the Clyde with the southern end

of Loch Lomond and the northern end with Loch Tay, providing a through route to Kenmore at an estimated cost of between £40,000 and £50,000. The ore from Tyndrum was cited as a key source of revenue (Lindsay 1968, 183–184). Only a short section (around half a kilometre) of the canal at the northern end of Loch Lomond was built, with turning space and landing stage.

How much Baron was responsible for suggesting the introduction of the improvements at the mine is not clear from the record; neither is the total sum of the initial outlay. Robertson has estimated that just under £8,000 was spent between 1838 and 1839 (Robertson 1992, 192). This investment is significant to the story of the venture as it set the scene for the next twenty years. The Marquis placed an ever increasing emphasis on recouping the investment.

Four levels, Long, McDougall's, Bryan's and New, were allegedly being worked (NRS, GD112/18/8/7) out of a total of nine, and in January 1839 Baron assured the Marquis 'that considerable profit will arise from the mining operations of the past year' (NRS, GD112/18/8/7/3). Baron did not wait to find out. He suddenly decided to leave and take his family out of the country. Whether or not Baron foresaw the financial difficulties is not made clear in the record. There was no compensating income recorded at the mine during his period of management (Robertson 1992, 192).

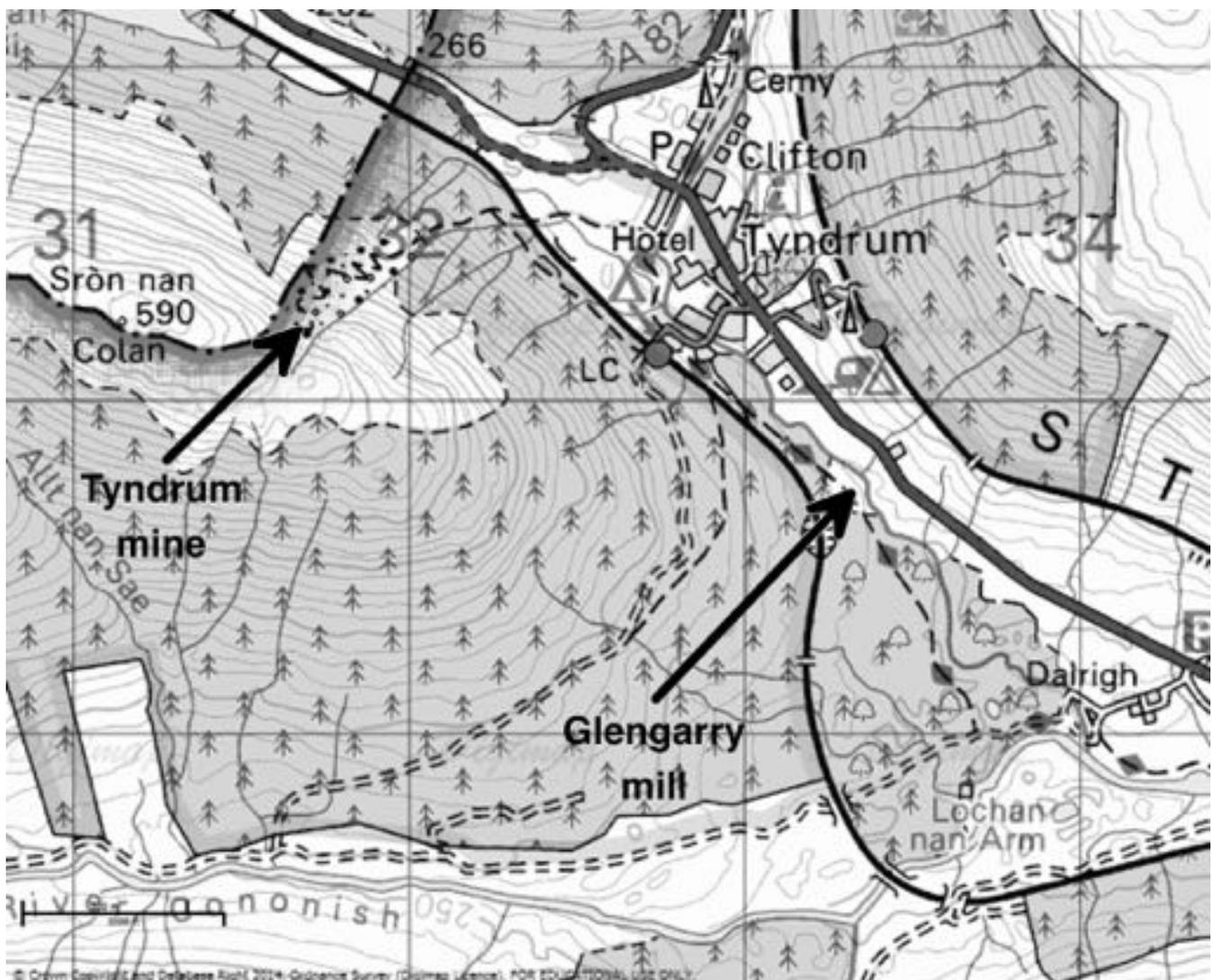


Fig. 3 Site locations

There had, however, also been problems with the Strontian miners over their bargains, which is also revealing. The men wanted payment by the fathom and not ‘under any consideration’ by the quality of the ore. These were experienced miners who would have had some knowledge of the viability of the operation; they were clearly not willing to share the risk (NRS, GD112/18/8/7/2).

Baron’s son Edward, who was currently engaged at Leadhills, offered his services to the Marquis upon his father’s departure, but he was perceived as too young to take on the responsibility of managing the operation (NRS, GD112/18/8/7/3). It is at this point in the history of Tyndrum that the German engineers, Odernheimer, Reichendorf and Thost, entered the picture.

German management at Tyndrum

Odernheimer, the first German engineer, arrived at Tyndrum shortly after Baron’s departure early in 1839 and remained until 1841. Odernheimer was accompanied by a colleague named Horstmann and a ‘practical miner’ known as Laubach who would teach the Tyndrum men mining skills (NRS, GD112/18/8/7/10). Neither professional nor personal details are recorded for any of the three men. For example, Odernheimer’s qualifications, his experience and how he was recruited are not known; neither are first names recorded. Odernheimer’s salary perhaps gives an indication of his expertise. He was paid £200 in the first year; this was increased to £250 in the second year, and from year three he would receive a percentage of all profits (Bainbridge 1980, 40).

Stephen Reichendorf replaced Odernheimer in 1847. Reichendorf had studied at the University of Heidelberg, had a background in both metal and coal mining and had previously worked in Austria, India and eastern Europe. He had met the Marquis in Paris and was persuaded to take up the position at Tyndrum by the Marquis’ enthusiasm for the mine’s alleged mineral potential and his promises that Tyndrum was ‘a very cheap place to live’ (NRS, GD112/18/9/5/25). Reichendorf’s stay in Scotland was short; he left for Valencia after three months.

Gustav Thost followed some two years later in 1849 and he remained until around 1859. Thost was a colleague of Odernheimer, had studied in his home town of Freiburg and had previous experience both in Saxony and Spain. He was essentially a fugitive from his homeland, having ‘taken the side of the Constitution of the Parliament of Frankfurt’ during the constitutional revolutions in Europe in 1848–49 (NRS, GD112/18/9/7/14). Shortly after his arrival in Scotland his property in Freiburg was confiscated and he elicited the support of Campbell in ensuring his family’s safe passage to Scotland (NRS, GD112/18/8/10/8).

The Germans found highland Scotland and conditions at the mine very different from their homelands, and there are many statements that ‘it is not the German way’. These appear to refer to three key elements: good diet and housing and strict discipline to maximise labour efficiency. Odernheimer described his style of management in relation to the workforce as ‘an almost religious point’, ‘to take care of the workmen’, ‘to be kind to them’, ‘it’s worthwhile’, he claimed, ‘they return plentifully’ (NRS, GD112/18/8/7/9).

Reichendorf in particular could not bear the solitude, the weather, the conditions and what he perceived as undue

interference from the Marquis’ factor. He resided at the Tyndrum Inn, where he described the walls as black with wet; at one point he asked for Mr Wyllie to be removed from his post (NRS, GD112/18/9/5/1–25). Reichendorf struggled with poor industrial relations and the lack of capital investment. All three managers found the pressure exerted by the Marquis to produce and process ore at minimum costs frustrating.

The Marquis wanted a return on his initial investment and as long as production remained at a low level he was reluctant to invest any further capital, yet at the same time he was keen to keep the mine working in the hope of an eventual bonanza. All Tyndrum’s mine managers were caught between a rock and a hard place and their working lives became increasingly difficult as time progressed and production continued to dwindle. Odernheimer’s, Reichendorf’s and Thost’s responses to the Marquis’ demands were two-fold: increase labour efficiency and adapt and modify existing technology to increase production. Whilst this study touches upon the management of the labour force, particularly in relation to Thost’s administration, the following sections concentrate on the key technological responses, particularly at the surface of the mine; this is followed by discussion of how successful the modifications and adaptations were in terms of the economic survival of the mine.

Adaptive strategies

Odernheimer

When Odernheimer first arrived at the mine he commented that the ‘last year of work’, under Baron’s management, ‘was only to clear out old levels’ and there had been little productive work. There were problems with water beneath Long Level and the ‘biggest part of the vein was already worked out leaving the remaining ore in long strings of no great length or depth’. He suggested that continued work ‘in all levels was worthwhile’ but a ‘good mining operation would not be founded on the borders of the old working’; he began trials north of the mine (NRS, GD112/18/8/7/9). Although details of its commencement are not recorded, a new level named after the ‘practical miner’ Laubach appears on plans drawn up in 1860 (BGS, 16592, 1860).

Odernheimer emphasised the ‘disorder’ at the mine which, he noted, ‘could not be rectified overnight’ (NRS, GD112/18/8/7/14). He damned the earlier investment in the crusher at Glengarry as ‘fool hardy and premature’ and despite the high cost of transporting the ore to Glasgow for smelting – estimated at 19% of the annual cost of running the entire operation in 1840 – he brought a halt to the plans for a smelter (NRS, GD112/18/9/2/3). This suggests that Baron perhaps made a wise decision in quitting his position.

By June Odernheimer was already under pressure, commenting that he would not pander to the Marquis’ desire for him to promise wealth (NRS, GD112/18/8/7/12). By December he was struggling with the attitude of the workforce, the severity of the weather and economies of scale. Tyndrum mine, he grumbled, ‘is too small an operation’ to pay (NRS, GD112/18/8/7/17). In response to the mounting difficulties Odernheimer began by adapting and extending the existing infrastructure at the mine site to both improve the efficiency of moving the ore around the steep hillside to the waggon way and to tackle the problem of increas-

ingly complex mineralisation (NRS, GD112/18/4/1/66–67). He had rails laid down in the main level (McDougall's) to the surface and had a primary crushing floor constructed at the adit mouth with a 'stampwork and moving hearth' to separate the lead ore from zinc blende and reduce the amount of waste rock and gangue minerals transported over the 1.5 kilometre distance to the crusher at Glengarry (NRS, GD112/18/8/7/15 and GD112/18/9/5/5–6). Shortly before his departure he also introduced washing and dressing at the entrance to New Level. It took a total of six months to process the mixed ore that had been stockpiled at the mouths of the adits, which gives an indication of the mineral wealth discarded as waste (NRS, GD112/18/8/7/20).

When Odernheimer arrived at Tyndrum there was no mechanism in place to transport the ore down the incline on the eastern flank of Minehill (marked 'Breadalbane's' on Fig. 4) to the waggon way, so to further increase transport efficiency he introduced a self-acting mechanism. This was an innovation that he takes credit for introducing into Scotland, described as 'full wagons pulling the empty ones to the top' (NRS, GD112/18/8/7/25). Ore had previously been moved around the mine site by use of wheelbarrows and ponies down a zig-zag path to the head of the waggon

way. The embanked route of the 'Breadalbane' incline and the pony path are both still visible at the site today, together with two further higher inclines (marked 'high incline' and 'middle incline' on Fig. 4; see also Figs 5 and 6) running vertically through the site to the primary dressing floor. Unfortunately, no details of these inclines are recorded in the documentary evidence. At the Glengarry crusher site Odernheimer introduced two 'German shaking herds', powered by the existing wheel, to tackle what he termed the 'tenace slimes' in an attempt to extract ever more ore from the waste rock (NRS, GD112/8/8/7/2). Every mine, he claimed, needed to find its own way of working; this sits comfortably with the notion that local conditions determine technological adaptations (Burt 1991, 254).

By June 1840 Odernheimer began to suspect his services were to be dispensed with, and hoped the Marquis would not be offended by his proposal to return to Germany in the coming year (NRS, GD112/18/4/1/166). In his request to return home, Odernheimer hoped that there would be a discovery of new ore, so that he could leave behind a 'legacy' before he left Scotland (NRS, GD112/18/4/1/166). Laubach's Level did not come to fruition. Odernheimer missed his homeland, found conditions at the mine and the

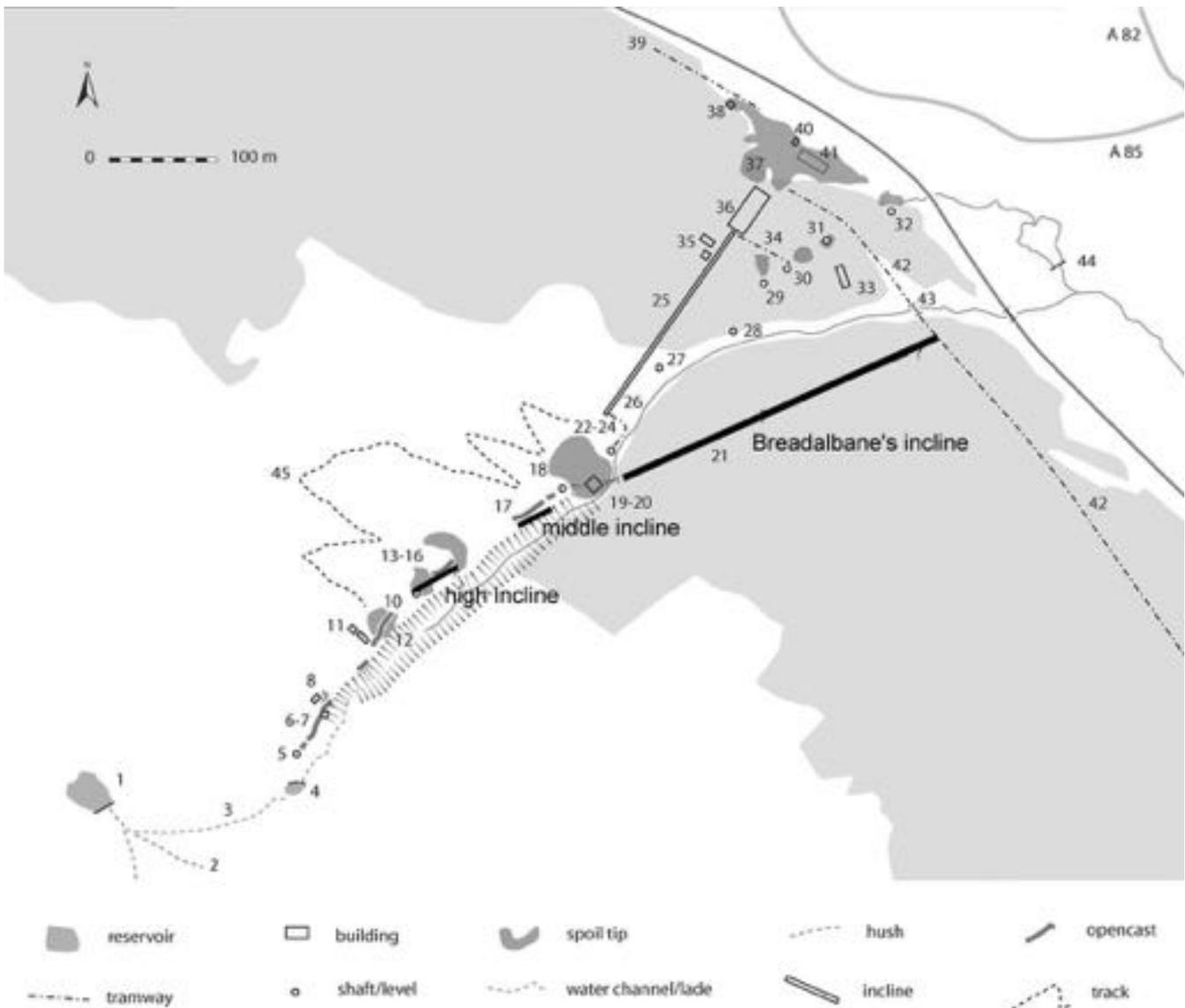


Fig. 4 Incline locations (© John Pickin)



Fig. 5 High incline (© John Pickin)



Fig. 6 Middle incline (© John Pickin)

climate dispiriting – one day of rain, he commented, ‘makes the whole place swimming’ (NRS, GD112/18/8/7/12) – and he was clearly not envisaging a substantial cut of the profits if he remained for a third year. He departed Scotland as planned in 1841 (NRS, GD112/8/4/1/180). During his period of management the mine made a total loss of around £4,500 (calculated from Robertson’s data: Robertson 1992, 192).

Crerar and Wilson

The Marquis immediately employed James Crerar, the company storekeeper, who was originally from Strontian, to manage his venture together with the current overseer at Tyndrum, Joseph Wilson. These two continued as managers until the arrival of Stephen Reichendorf in 1847. Their joint reports across the period predictably focus on justifying the increasing cost of the bargains. Although there was

exploratory work, for example on Ben Odhar, and development work in the existing levels, particularly in Stamps Level, Crerar and Wilson were fairly gloomy in their overall outlook. The explorations were yielding very little and they grumbled that the ground was becoming increasingly hard; yet these comments were tempered by the occasional optimistic comment suggesting potential improvements in the quality of ore. But by February 1844 the crushing mill was standing idle, the rollers were worn out by the hardness of the rock, and later that year the men were back barrowing ore round the site (NRS, GD112/18/8/9/1–34).

This period of management is largely superfluous to the discussion of technological adaption: Crerar lacked practical mining experience and neither he nor Wilson held the authority to implement changes. Their role was simply to keep the mine operational. Their story, however, is important for historical continuity and for the context of Reichendorf’s subsequent difficulties as mine manager. For similar reasons Robert Harrison’s period of supervision is briefly discussed below in order to show what had been happening between Reichendorf’s departure and the arrival of Thost.

Reichendorf

Reichendorf’s initial assessment of the mineral wealth at Tyndrum was fairly bleak – ‘it is not a rich field’ he commented – but, as with Odernheimer, his brief was to make the mine a financial success (NRS, GD112/18/9/5/3). His key responses on arrival were again to increase production efficiency, particularly in terms of the workforce (NRS, GD112/18/9/5/9). He also attempted to tighten up the system of accounting, which was integrated with both the company store and other operations of the estate. Predictably there was tension between Reichendorf, Crerar (who was back running the store) and Wilson. Wilson, whom Odernheimer had previously described as ‘more blockhead than scoundrel’, was dismissed for dishonesty by Reichendorf shortly after his arrival. In response, Wilson called his fellow workers to strike and industrial relations at the mine deteriorated.

Reichendorf too was disparaging about the investment in the crusher at Glengarry – he referred to it as ‘that expensive mill’ – but bemoaned the fact that there was no smelter; to have constructed both, he claimed, would have made for a wiser investment (NRS, GD112/18/9/5/7). The desire to smelt on site may also reflect the fact that John Wyllie, the estate factor, controlled the sale of all processed ore, and Reichendorf found it very difficult to establish the profitability of the mine.

In terms of technological adaptations Reichendorf built on the existing transport infrastructure initiated under Odernheimer’s management and introduced what he termed ‘wooden canals’. From Reichendorf’s descriptions these may have been ore chutes from the upper workings down to McDougall’s Level so that ore could be transported by rail to the primary crushing floor (NRS, GD112/18/9/5/24). To streamline transportation further, he also proposed double track or passing places in McDougall’s Level so that empty waggons could be ready and waiting to be loaded (NRS, GD112/18/9/5/18). In effect he was adapting Odernheimer’s original adaptations. Reichendorf’s stay in Scotland was too short for his plans to come to fruition and, reflecting the poor industrial relations, the wood from the ore chutes was

repeatedly pilfered and used to construct a pig sty at the Tyndrum Inn (NRS, GD112/18/9/5/24).

Reichendorf arrived at Tyndrum in June, by July he was asking permission of the Marquis to leave, and by September he had fled to Valencia indicating that the Marquis had reneged on the terms of his contract. In a ten page letter addressed to the Marquis, Reichendorf detailed accounts of alleged mismanagement and corruption at the mine involving Crerar, Wilson and Wyllie.

According to Reichendorf the three men were operating the mine to their own advantage rather than in the financial interest of the Marquis. They turned a blind eye to the constant pilfering of material from the site, charged wood for the church to the mine accounts and, in particular, Crerar allowed the men food and whisky from the store irrespective of their ability to pay or their mounting debts, whilst at the same time he exercised very little supervision and the men rarely fulfilled their bargains (NRS, GD112/18/9/5/23).

To what extent Reichendorf's allegations were true is difficult to assess. Certainly, when Reichendorf arrived at Tyndrum and for the duration of his short stay the Marquis was in London, and Wyllie persistently denied Reichendorf any direct communication with him. He also undermined Reichendorf's authority by repeatedly removing 'a quarter' of the mining labour force to work on the construction of the canal at the north end of Loch Lomond (NRS, GD112/18/9/5/23). There is no copy letter in the archive recording the Marquis' response to Reichendorf's resignation letter. Wyllie's correspondence, in contrast, survives. On Reichendorf's sudden departure he wrote that Reichendorf was too young and 'exceedingly active'. Wyllie intimated that he was also overambitious in his aims for the mine and, perhaps somewhat hedging his bets, he described Crerar as 'addicted to drink'.

Harrison

In the two year interim period between Reichendorf's resignation and Thost's appointment the mine was managed by Robert Harrison. There is no indication in the records of where Harrison was from or his background or previous employment. His early reports support the idea that Crerar, Wyllie and Wilson had run the mine down. Harrison ordered repairs to the railway, the reservoir and the crusher. New Level had become 'impassable' and 'bad and dangerous' (NRS, GD112/18/9/6/10/15). It was cleared and retimbered. He also reported that the labour force were 'not disposed to work' and he employed 'new hands' both at the surface and underground (NRS, GD112/18/9/6/10/13). Crerar was still minding the company store and Harrison reports a disagreement over timber in November 1848 between Crerar and Griffiths Roberts, the overseer at Tomnadashan mine, the Marquis' copper venture on south Loch Tayside, but otherwise operations ran smoothly (NRS, GD112/18/9/6/10/19).

Harrison was successful in discovering promising new veins in three of the original levels at Tyndrum – Stamps, New and McDougall's – although these were not proven long term. Harrison worked with what was on site without introducing new technology and infrastructure or adapting that which already existed. Although he appears to have had more authority than Crerar and Wilson in terms of the day to day operation of the mine, the extent of his control is unclear. He made no suggestions for change, neither did

he place any significant financial demands on the Marquis other than to request copies of the *Mining Journal* (NRS, GD112/18/9/6/10/21). There were certainly opportunities to apply engineering knowledge and skill to increase productivity. For example, New Level was 100 yards below the top of the incline to the waggon way that led to the secondary crushing floor at Glengarry. In order to load ore onto the waggons it had to be barrowed up a steep slope with a gradient of around 1 in 6 (NRS, GD112/18/9/7/12).

Nevertheless, Harrison oversaw a successful period at the mine with the discovery of new ore, despite the 'great gloom than hung over the lead market' (NRS, GD112/18/9/6/13) and this meant he would have been under less pressure to increase efficiency. When Thost was engaged Harrison remained employed at Tyndrum, but as the overseer, and he was clearly subordinate to Thost. For example, at one point he was tasked with locating a bed and fresh linen for Thost (NRS, GD112/18/9/7/24).

Thost

Thost had been engaged originally to report on the copper mine at Tomnadashan. He had responded to an advertisement placed in the *Mining Journal* by the Marquis (NRS, GD112/18/9/7/14). How and why the transition occurred from writing a one off commissioned report to managing the Marquis' entire mining operations is not recorded. Of the three Germans it was Thost who remained in post for the longest period but, given his fugitive status, he may have perceived that he had little choice. He had struggled to find work in England and had hoped to go to America (NRS, GD112/18/9/7/14).

Thost arrived in Scotland with very limited skills in written or spoken English but was fluent within a few months and, once he was reunited with his family, he settled comfortably into highland life. Although Thost, like his predecessors, never gained autonomy over the finances or the shipment and sale of ore, of the three Germans, he sustained working within the convoluted chain of command and was not averse to manipulations himself. He would often be late when he returned from leave or holiday and in one instance he managed to negotiate a pay rise with Wyllie while the Marquis was away in London (NRS, GD112/18/8/14/22 and GD112/18/8/16/32).

Much of Thost's activity was focused on the Marquis' peripheral mining ventures: the operations at Tomnadashan, proving the recent discovery of a vein of lead ore at Ardtalnaig on south Loch Tayside, and the discovery of a small nugget of native gold at Lochearnhead (NRS, GD112/18/8/16/1). His initial thoughts on Tyndrum concerned establishing 'profitable methods of working', getting 'the minerals from every place' and 'preparation with water powered machinery' (NRS, GD112/18/9/7/19). Like his predecessors, Thost focused upon improving efficiency in the dressing process and in the movement of the ore around the site at Tyndrum, and upon increasing labour efficiency. In contrast to Reichendorf and Odernheimer, Thost also emphasised safety as well as the wider wellbeing of the workforce to improve productivity. He used technological adaptation to achieve this and, predictably, industrial relations under his management were generally good.

A prime example of this is his response to the operation of the 'Breadalbane' incline, originally modified during

Odernheimer's period of management. By 1854 Thost was expressing concern that it was too long for 'waggoning', particularly using hemp rope, and he was concerned that there would be an accident on which he comments, this '[I] dare not pass over with silence' (NRS, GD112/18/8/14/21). Although it was a somewhat backward step, throughout 1855 ore was once again being transported from the upper workings on Minehill to the head of the waggon way by pack ponies (NRS, GD112/18/8/16/9). By 1858, Thost had solved this particular problem with the use of angular piping or troughs filled with water running down the incline. He claimed that 12½ cubic feet of water was sufficient to carry a total of 4 tons 4 cwt 32 lb of lead ore in 2 inch pieces down the incline. Angular troughs, he claimed, can carry anything from 2½ inches down to a fine powder at a 'trifling inclination'. Although Thost refers to the angular troughs as an 'invention' it is likely this was an adaption of Reichendorf's earlier introduction of wooden canals. Nonetheless, Thost presented his 'invention' at the Royal Scottish Society of the Arts, where he also advocated its use by road trustees both for conveying road metal from quarry to depot and for street sewers to prevent clogging in the drains (*Caledonian Mercury*, 26 July 1858; also see Easson 2011, 61).

Thost also discovered poor underground conditions, described as 'wretched and dangerous', due to lack of timbering and attempts to save money on the use of wood (NRS, GD112/18/4/1/65). Poor ventilation had also been problematic throughout the mine's history and was hindering development work (NRS, GD112/18/9/5/10). New communications were cut between levels and Thost also erected a 'wind engine' in May 1857 to improve the quality of the air via a system of pipes and 'fanners' (NRS, GD112/18/9/5/10). There are no descriptions of the machine, its location or its style of construction other than that it was probably hand powered. Thost described how 'three little boys are able to satisfy by dividing 16 hours between them' (NRS, GD112/18/9/1/38).

All three Germans preferred a day labour rate to the bargain system, but it was Thost who initiated changes to encourage work discipline, remove the need for an overseer thereby saving more expense, and to help tackle the problem of debt that had remained since Crerar's period of management and which, according to Thost, reduced the incentive to work. The miners' wages were eventually cal-

culated by waggon load of ore and a system of rules with fines was introduced (NRS, GD112/18/9/27).

Another key example of Thost combining the wider well-being of the workforce and technological adaption to improve productivity was his addressing the problem of water supply at the mine site. The primary dressing floor, originally introduced by Odernheimer, was constantly out of sequence with the crushing mill at Glengarry. This resulted in unprocessed ore stockpiled at the mine and the surface workers were laid off at both dressing floors with no pay. Thost simply repaired the dam and reconstructed a disused leat from the western side of Minehill that was built during the Scots Mining Company lease (NRS, GD112/18/8/15/4). Much of the revetment and stonewalling of the leat is clearly visible at the site today (Figs. 7 and 8).

Thost also persuaded the Marquis to fund his new design for ore dressing at the Glengarry mill site. It permitted the self-acting reduction of 2½ inch pieces of ore to a fine powder using a series of stepped grates reducing in size, again utilising Thost's right-angled inclined troughs together with a corresponding right-angled hoe. He published details of his 'New Arrangements for Cleansing, Sizing, Trunking and Buddling Ores at the Tyndrum Mines' in the *Mining Journal* (copy article with plates at NRS, GD112/18/8/9/4; also see Fig. 9 below, based upon Thost's drawings) and wrote to Breadalbane to request that he personally inspect the apparatus and support its patent (NRS, GD112/18/8/16/13). On a less grandiose scale, to address the constant repairs to the crushing rollers Thost had these cast to a new design so that one guided the other and reduced the potential for accidental damage (NRS, GD112/18/8/14/27; also see Fig. 10, based on Thost's drawing).

In July 1860 Thost wrote to the Marquis and made reference to his 'particular circumstances', which prevented him from obtaining a passport from 'any country'; he requested that the Marquis support his application to travel to France and Switzerland with his wife and two daughters. Interestingly, Thost was then signing his letter Charles Henry Gustav Thost (NRS, GD112/18/1/5/11 and 17). What is not clear in the record is whether this trip to the continent was permanent, or whether Thost's services were simply being dispensed with, and why. The Marquis had entered into negotiations with George Henwood early in 1860 for a survey of all mines, including Tyndrum, and Thost disap-



Fig. 7 Route of leat



Fig. 8 Leat wall

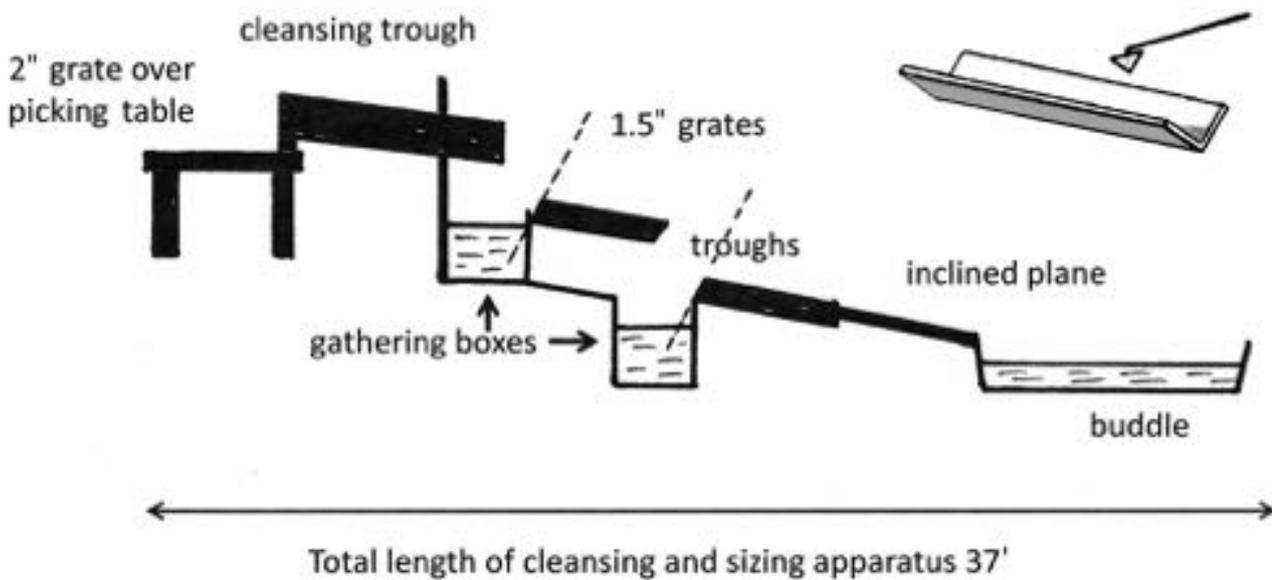


Fig. 9 Cleansing and sizing apparatus: sketch of Thost’s original plates. (NRS, GD112/18/8/9/4). Detail, top right, is a conjectural reconstruction, based on Thost 1860, of the right-angled inclined trough and triangular hoe, used in the apparatus.

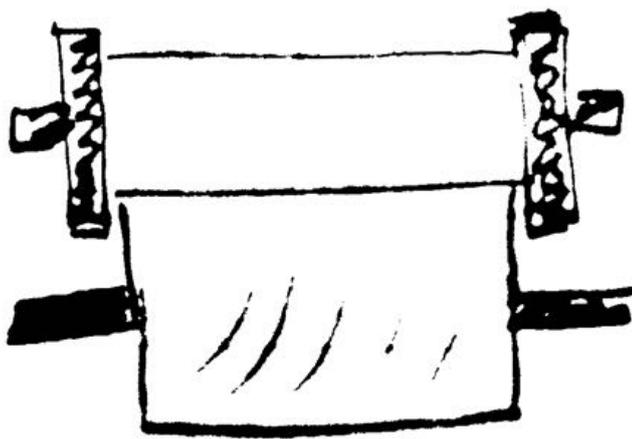


Fig. 10 Crushing rollers: sketch of Thorst’s original drawing (NRS GD112/18/8/14/27)

pears from the record in 1860. There is no trace of him or his family in the 1861 Census.

Economic resilience

To what extent did the managers’ technological adaptations of the existing infrastructure and machinery increase efficiency and prolong the working life of the mine? Production figures, although sparse, indicate that the amount of ore extracted and metal produced increased during Thost’s period of management. Production rose from 60 tons of ore and 43.8 tons of metal in 1850 to 130 tons and 94 tons respectively in 1856 (Burt, Waite & Atkinson 1981, 156). In terms of increased output Thost’s adaptations were a success, albeit a short-lived one. However, if the price of Tyndrum ore sold at Holywell is considered, it reveals a very different picture: the ore only ever received the lowest amount, which prompted Thost to consider stockpiling the poor quality ore and selling only the richer stuff to ensure a better price (Easson 2011, 61 and NRS, GD112/18/9/8/11). Income during the period 1850 to 1856 was roughly £2,500, which was a marked improvement on the zero amounts

recorded during the preceding four years, but expenditure for the same period amounted to just under £11,000 (Robertson 1992, 189–217, 192). Given the financial losses under Odernheimer’s management, his decision not to wait for a share in the profits that were due for his third year of employment was arguably prudent. Production began an overall slow trend of decline from 1856 onwards (see Table 2) but mining did not cease until 1865, some three years after the death of the Marquis and the Breadalbane estate executors called a halt to all mining activity (Wilson 1921, 95).

Although what was an ailing and exhausted mine from the outset of the Marquis’ tenure continued to work for almost thirty years, technological adaption had not extended its economic viability and substantial amounts of money were wasted in what Firsoff described as a ‘brave attempt to carry on [mining] at a loss’ (Firsoff 1954, 133).

The mine essentially operated to bolster the over-optimistic ideas of the Marquis and to keep the estate tenants in employment. Reichendorf noted at the end of his resignation letter that the Marquis kept ‘an emu and deer and pheasants

Table 2 Production

Year	Lead ore (tons)	Metal (tons)	Silver (ounces)
1857	61	42.5	93
1858	54	37	160
1859	69	40	160
1860	80	57.2	229
1861	60	43	172
1862	67	47.5	120
1863	46	32	64
1864		no data	
1865	49	35	0

(Data from Mineral Statistics, cited in Burt, Waite & Atkinson 1981, 156)

and a museum and other remarkable things' for his pleasure and 'not for any use'. Reichendorf went on to state that he was of the opinion that, in the same way, the Marquis had 'a mining officer, miners, a mine, a railway, a crushing mill all in the greater glory of the Lord', suggesting the mine was little more than a 'show piece' as opposed to a viable economic operation. His comments, however, do not accord with Thost's succeeding management of the venture from 1849 onwards and his optimistic outlook when he claimed to have taken 'the mine onto a new and better road' and wrote that he was hopeful of 'carrying on continuous economical and reasonable mining' (NRS, GD112/18/8/9/44). George Henwood commented that the mine was run for 'the employment of the poor of Clifton village' (Henwood 1860, 715), Clifton, now subsumed into Tyndrum, having been the name given to the original row of miners' cottages built in the 1730s. Henwood too had a somewhat difficult relationship with the Marquis. For example, he became increasingly frustrated with the lack of response to his letters and the Marquis' failure to confirm the terms of his employment. He did, however, eventually survey the mineral workings within the Breadalbane estate (NRS, GD112/18/8/15/30 and 35; GD112/18/1/5/5).

The difficult and often complex relationships that all the external managers had with the Marquis make assessment of the validity of their comments difficult. Reichendorf had essentially reneged on his contract of employment and was unlikely to portray the mine in a good light. It is unclear whether Odernheimer and Thost colluded with the over-optimistic ideas of the Marquis. Thost certainly had a vested interest in pandering to his hopes and dreams; he was a refugee in Scotland and reliant on the favours of his employer.

Although there is no direct evidence in the record to suggest that estate employment was a primary aim of the Marquis, he never wavered in his belief in the great mineral wealth of his land. There is, however, the question of paternalistic relationships and public duty; whether by default or design, the mine did support local employment. This is clearly seen in the case of the Strontian men brought in by Baron. The strategy engineered between Wyllie and the Marquis was to ensure that the mine would become independent of outside labour: the Strontian miners would be used to train the young men of Tyndrum and the surrounding settlements in mining skills and then they would be removed (NRS, GD112/18/8/7/2). A local workforce was eventually achieved. For example, throughout the 1850s, excepting a handful of men at Tomnadashan and James Crerar, the lists of miners employed all reveal local estate names (see, for example, NRS, GD112/18/9/8/15).

What is quite interesting is the Germans' failure to explore the potential for adapting processing technology to work the zinc blende and the other gangue ores which could potentially have prolonged the economic viability of the venture. Shortly before his departure Thost began to sort and stockpile blende rather than dumping it as waste (NRS, GD112/18/8/15/). Yet even the Tyndrum Lead and Zinc Company, who worked the mineral lease from 1916, failed to realise a profit from both zinc and lead ores. This was despite the introduction of modern crushing and separation technology. It prompted old Tyndrum miner John Macfarlane to comment that the Company had made so much money abroad that they would not mind operating at a

loss (Firsoff 1954, 133). Neither small adaptations of existing technology nor the introduction of new technology could overcome the poor and declining quality of the lead ore.

Conclusion

The majority of the studies in this volume examine key developments in mineral extraction and exploration, such as mechanical cutting, drainage and boring. In contrast, this study has explored technological change on a much smaller scale: the adaptation and modification of existing infrastructure and technology and its role in increasing productivity and sustaining the economic viability of extracting a finite resource.

The survival of substantial documentary evidence for the surface operations at Tyndrum mine permitted a focused case study approach. The study reveals an intriguing history of mismanagement, personality clashes and potential corruption; in many ways the story was ideal for an assessment of the efficacy of adaptive technological strategies. The nineteenth century history of the enterprise is one of hasty and ill-considered extensive capital investment in a mine with complex mineralisation that was nearing exhaustion, based on the landowner's grandiose belief in the mineral wealth of both the operation and his landed estate. Reichendorf cut his losses and reneged on his contract of employment, but Odernheimer and Thost both had a vested interest in realising a profit: Odernheimer in terms of salary, although he cut his losses, and Thost in terms of his refugee status. All three Germans tackled the movement of ore around the site and the dual problem of a dwindling supply of quality ore and complex mineralisation by making small adaptations and modifications to the existing arrangements. Henwood suggests that there was no continuity between managers but he was referring specifically to underground development work at Tyndrum; at the surface each engineer expanded and developed the work of his predecessor. In theory their modifications should have reduced operating costs and increased the opportunity to achieve the ideal concentration of ore for smelting, at roughly 60–70%; they should ultimately have increased the profitability of the operation (Burt 1983, 1–10). Only Thost managed to increase the production of dressed ore, albeit very briefly, but the poor quality of the ore was reflected in the price. Even in a good year expenditure always exceeded income. It was the Campbell family fortune and the Marquis' faith and conviction, rather than technology, that allowed the venture to continue operating. Although it was not what the Marquis desired, or perhaps even perceived, nonetheless the end result was, as Henwood suggested, a charitable public works.

What the study does highlight is the success of technological adaptation in meeting local conditions. The German engineers were responding to a very specific set of circumstances, both geological and practical, and also the unique situation created by their employer's desire for rich mineral deposits and great mineral wealth. They were essentially caught in a cleft stick so they simply applied their cumulative knowledge and experience of the mining arts to overcome the practical difficulties while neither challenging nor supporting the erroneous beliefs of the Marquis. This application of practical skill supports Burt's original argument, discussed in the opening section, that technological change occurs where necessary and without formal diffu-

sion mechanisms (Burt 1991, 249–271, 254). Ultimately, for the German engineers, the difficulties at Tyndrum mine could not be solved. The venture was exhausted of viable lead ore and worked beyond its economic viability.

Acknowledgements

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Abbreviations

BGS British Geological Survey
 NRS National Records of Scotland
 NLS National Library of Scotland
 OSA Old Statistical Account of Scotland
<http://stat-acc-scot.edina.ac.uk>

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