Bitumen paper pipes and technology transfer on the Victorian goldfields

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Historians of mining technology in Australia have traced the introduction of many new machines and processes for the extraction and processing of ores, observing the pulses of innovation that have characterised the industry at different times. This was the case, for example, in Victoria in the 1850s, where Davey has described the 'adventurous and energetic' nature of technological innovation, and at Charters Towers in Queensland during the 1880s and 1890s.[1] In cases where new approaches were successful, widely adopted and of long-term impact on the industry, such as roasting, dredging, chlorination, or cyanidation, the willingness of investors to use the new technologies can appear in retrospect to be logical and inevitable.[2] Successful technologies became common features of mining landscapes, but their ubiquity can obscure the process of trial, risk and error involved in their early use and the many failures and blind alleys that were negotiated along the way.

If history favours the successes, archaeology highlights the failures. Graham Connah has observed that the industrial archaeology of Australian mining provides more evidence of failure than it does of success, due largely to the nature of the archaeological record.[3] Where a mine is successful the location tends to be used and reused over long periods and in the process the evidence of what has gone before is obscured or destroyed. The archaeological evidence survives best in cases where the mine has failed and the miners have walked away, leaving in place machines and abandoned workings as a record of what went wrong. In this paper we are interested in the processes by which the mining industry learned about and trialled new technology. The combination of archaeological and documentary evidence of one short-lived experiment allows the full sequence of discovery, adoption, and abandonment to be traced and highlights the social context of technology transfer and the particular local circumstances that favoured innovation.

This case study concerns the use of bitumen paper pipes in the sluicing industry in the early 1860s, as an example of a new technology that was taken up rapidly on the goldfields and abandoned soon after when it was shown not to work. Pipes made of bitumen-covered paper were invented in the late 1850s and promoted as a cheaper, lighter alternative to conventional cast iron pipes. Such claims were hailed with enthusiasm at a time when entrepreneurs were rushing to provide infrastructure to meet the growing demand for water on the goldfields, particularly for the sluicing of alluvial deposits, which at the time was a very lucrative branch of mining. While the courts adjudicated competing claims for water and established a regularised system of issuing water rights, companies large and small hurried to build networks of dams and channels to convey the water to where it was needed. Water was also required in other branches of mining and for domestic use, and the cry for greater storage and better reticulation of water supplies resounded across the goldfields.[4] Pipes were required for collecting and distributing water and anything that could facilitate the construction process and save on costs was eagerly sought.

Several sluicing companies on the Victorian goldfields thus decided to use the new bitumen pipes in water supply networks, but once installed the pipes quickly proved to be unsatisfactory. Ultimately all the companies replaced bitumen with cast iron pipes and the experiment was forgotten until the discovery in 2012 of archaeological evidence for the bitumen pipes in forest areas near Creswick in central Victoria. Research has revealed numerous press reports about the pipes and the intense interest in this invention for its potential application in mining. The excitement surrounding the introduction of the pipes and their subsequent abandonment in the Creswick forest demonstrates the volatility of mining at the time and the frantic, almost desperate quest for better methods to secure water.

The survival of both archaeological and documentary evidence for several companies around Creswick provides a useful focus for discussion. Creswick is a small goldfield about 18km north of Ballarat. Gold was first discovered in the area in September 1851, and by 1854 there were several thousand miners working alluvial deposits in creeks and gullies around the township.[5] Good supplies of water were needed for sluicing the claims, and by 1854 miners began constructing races and dams to bring water from higher ground to the south and east.[6] The region was ideally suited for sluicing methods as its situation on the crest of the Great Dividing Range, and abundant shallow alluvial deposits, meant that both the elevation and water needed for sluicing were present. At the time bitumen pipes were being promoted, a number of major sluicing companies were building water races at Creswick, and ultimately a network of races over 170 kilometres in length served the area.[7]

Bitumen pipe technology

Bitumen refers to a group of closely related and naturally occurring hydrocarbons found in many parts of the world, and includes pitch, tar and asphalt.[8] Possibly first discovered in natural soaks, bitumen has been known and used for thousands of years as an adhesive and sealant in Palestine, Mesopotamia, Persia, the Indus valley, China and elsewhere.[9] Pliny the Elder described Roman uses for bitumen to treat various medical complaints,[10] while 'Greek fire' involved the use of pitch and lime as an incendiary in ancient warfare.[11] By the seventeenth century, tar for caulking ships was produced by the distillation of wood, coal and shale, and in the 1830s and 1840s asphalt was being used for pavements and road surfaces in many urban areas, including Paris and London.[12] Tar-paper roofing was developed in the United States in the 1850s, made by rolling paper through vats of tar in a process similar to that used to make bitumen pipes in the 1860s.[13] Production of bitumen also increased quickly at this time due to the rapid development of the petroleum industry in Europe and the United States, with bitumen produced as a by-product of refining kerosene and fuel oil.[14] By this stage something of a mania had set in for bitumen products, generating 'an industrial fever not unlike the celebrated South-Sea Bubble', which lasted several years until the industry settled down to routine production.[15] By this time bitumen was used for a wide array of industrial products including cable insulation, paving and roof tiles, due to its availability, low cost, elasticity, adhesiveness, durability and water resistance.[16]

Widespread experimentation with bitumen-based products resulted in the development of bitumen paper pipes. M. Jaloureau was a French contractor involved in laying bituminized pavement in Paris in the 1850s. Reports indicate that on one occasion a roll of paper covered with a bituminous compound was laid aside in a coil. It became so strong and rigid as to suggest the idea of making pipes from the material.[17] The process was patented in 1859, and involved melting bitumen and chalk, passing paper through the liquid, and then rolling it onto a cylinder of the required diameter. Such pipes were reported to be one quarter the cost and one-fifth the weight of cast iron pipes.[18] Previously, M. Chameroy in France had applied bitumen as a lining to pipes made from sheet iron riveted into shape, but the thin metal caused the pipes to collapse when used in large diameters.[19]

In 1860 *The Argus* newspaper reported the invention of bitumen pipes in London by Mr John Kennedy, who seems to have enjoyed government and royal patronage for his pipes.[20] Charles Newbold of Nottingham was also working on bitumen pipes in 1860 and he paid considerable attention to the sockets and flanges by which his pipes were to be joined.[21] The English excise duty on paper was removed in the following year, and soon afterwards a coarse brown paper pipe was made in London by dipping the paper in tar and rolling it around a cylinder.[22]

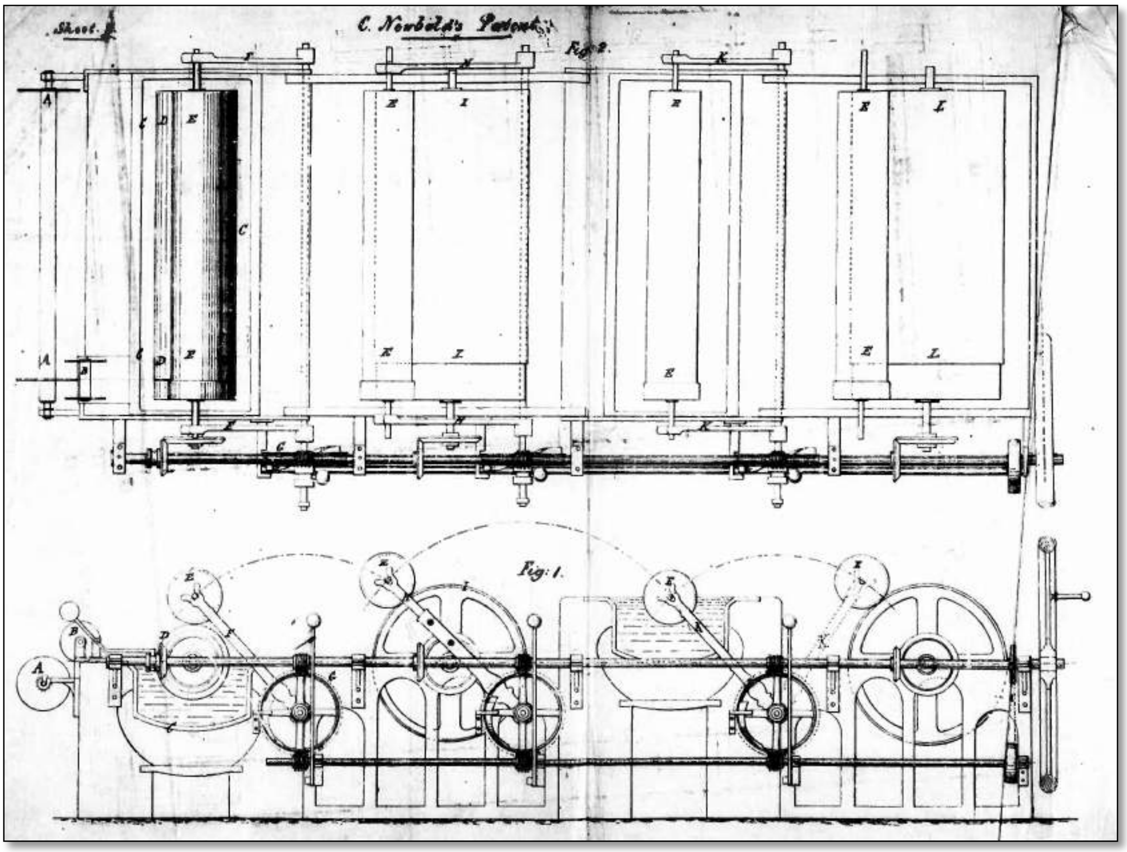
The process of manufacturing bitumen paper pipes required a long roll of paper cut to the same width as the pipe to be made, a vat of heated liquid bitumen and a series of cylindrical rollers. Pipes made were normally 6 feet 6 inches (1.98 m) long, and varied from two inches (51 mm) to 24 inches (610 mm) internal diameter. The pipes could be made in lighter grades for gas supply and drainage work, to be subject to relatively little pressure, and in heavier grades for mains water supply.[23]

Substantial amounts of paper were used in manufacturing the pipes, including the strong brown wrapping paper typically used by grocers. A pipe of six inches (152 mm) diameter required 26 yards (23.8 m) of paper, while a pipe of 13 inches (330 m) diameter required about 100 yards (91.4 m). By the mid-nineteenth century long spools of paper, including those used for wallpaper and newsprint, were commonly manufactured on continuous paper-making Fourdrinier machines.[24] Paper was generally made from a mix of cotton and linen rags, waste paper and other fibrous materials including straw, hemp and esparto grass. The use of cheap wood pulp for paper, which was developed in Europe and the United States from the 1860s, probably occurred too late to influence the manufacture of paper bitumen pipes.[25]

The paper was first wound upon a feeding roller and then passed gradually on to a lower cylinder that revolved continuously in a cauldron or trough of heated, liquid bitumen. Some factories used a Chilean mill for crushing carbonate of lime to a powder that was then added to the bitumen compound,[26] while Newbold's patent specified the use of distilled coal tar, or a combination of natural bitumen and Trinidad asphalt[27] mixed with India rubber or gutta percha.[28]

The paper, thoroughly coated with bitumen, was then transferred to a roller or mandril of the same internal diameter as the intended pipe. The surface of this cylinder was first prepared with a thin layer of oiled paper to permit the pipe to be more easily removed. When the requisite length of bituminized paper had been rolled onto the cylinder, the assembly was transferred to a sand table to consolidate the bitumen and paper and then dipped into a second trough of bitumen to provide an overall coating. When cooled, the newly formed pipe was slipped from the cylinder and the interior was treated with a further bituminous preparation to provide a smooth surface. The pipe was then taken to a lathe to remove the rough ends and make the article ready for market.

Figure 1: *Plan and section drawings of Charles Newbold's paper and bitumen pipe machinery*



Source: State Library of Victoria, SF608 Part II, specification 353, p. 8 (drawing 1) 9 July 1860.

A variety of other pipe materials was available in this period and bitumen pipes needed to demonstrate their advantages over a range of competing products in terms of price, weight, performance and durability. The most common pipe material was cast iron, with large quantities of iron pipes imported from Britain to Australia during the gold rush. Numerous colonial iron foundries were established to produce iron pipes, while stoneware and glazed earthenware drainage pipes were widely manufactured in colonial potteries by the 1850s.[29] Tongue-and-groove wooden stave pipes were developed in Britain in the early nineteenth century, and a large shipment was imported to Victoria in 1856, while others were used for sewerage at the Fremantle Gaol around the same time.[30] Pipes and hoses made from gutta percha were also widely available by the 1850s.[31] In addition, lead pipes and galvanized iron pipes were manufactured in Melbourne in the 1850s and 1860s, and wrought iron water pipes were available by the 1880s.[32] Parts of Melbourne's Yan Yean water supply system used wrought iron pipes coated with asphalt, a technology imported from California in the 1880s.[33]

In the colonial market the clear benefits of bitumen pipes were their cheaper price and lighter weight than iron pipes. A standard length of 9-foot (2.74 m) cast iron pipe, for example, with an 8-inch (203 mm) bore and a wall ⅝ inch (16 mm) thick, weighed 501 pounds (227 kg) and cost approximately £5.[34] A heavy grade 8-inch bitumen pipe, however, cost less than half as much and was about one sixth the weight of iron.[35] Freight and handling were also important factors. The first rail line to the interior of Victoria was the line from Geelong to Ballarat, which opened in 1862. As other areas were not reached by rail until years later, all heavy materials had to be hauled by horse or bullock wagon over poor quality roads. Bitumen pipes were thus cheaper both to buy and to transport.

Bitumen pipes in Victoria

The invention of bitumen paper pipes coincided with the boom in development of Victorian water infrastructure, and plans were quickly in place to bring the new technology to the colony. John Kennedy's patent was extended to Victoria by an agent, possibly Charles H. Lyon, who received a Victorian patent (No. 319) in March 1860[36] and another Victorian patent (No. 353) was granted in July 1860 to Charles Newbold.[37] There were also several unsuccessful patent applications at this time made by the brothers Paul and Alexander Joske, including plans for pipes made of paper, cloth, wire gauze or thin metal soldered with waterproof cement; of vegetable fibre combined with bitumen; and fibrous materials combined with bitumen under hydraulic pressure.[38] In 1864, a Victorian patent (No. 718) was granted to B.H. Dods for wooden pipes embedded in 'plastic cement' composed of bitumen, silica and other materials, but it is not clear if these were ever manufactured.[39]

Colonial rights to manufacture bitumen paper pipes were held by the partnership of Captain William A.D. Anderson and Paul de Castella, who established a paper pipe factory by the Maribyrnong River at Flemington in Melbourne in 1860. The firm was known as the Patent Bitumenized Pipe Company (PBPC), with offices at 127 Flinders-Lane East and Pall Mall in Bendigo. It appears to have commenced operating in November 1860, with H.A. Dalton serving as company manager and Frederic Moore as the company engineer.[40] Around 20 employees worked at the factory, which could make up to 300 yards (274 m) of pipe each day.[41]

Both Anderson and de Castella were well connected and able to use their networks to help generate publicity for their new enterprise. Anderson (1829-1882) had served as an army officer, assistant gold commissioner, magistrate, MLA and commissioner for Melbourne's water supply before his involvement in pipe manufacture, and in 1862 he was appointed Colonel Commandant of the Victorian Volunteer Force. Paul de Castella (1827-1903) was born in Neuchâtel, Switzerland and arrived in Melbourne in 1849. He acquired several major pastoral properties and became an important vigneron with his brother, Hubert. In 1856 he married Elizabeth Anderson, sister of William Anderson and the two men became brothers-in-law.[42] They promoted the bitumen pipes in several ways, including an entry at the Victorian Exhibition of 1861, for which they were awarded a First-Class Certificate.[43] Around the same time they commissioned a series of tests on the pipes, conducted by a committee of senior government officials, and the favourable results were reproduced as advertisements in the press.[44]

Barrels of bitumen were imported from various sources, including Trinidad, which could be shipped to Melbourne from the West Indies for about £5 per ton.[45] Bitumen tars were also widely produced in North America, Europe and the Middle East.[46] The large quantities of paper required for pipe manufacture also had to be imported, as production of paper on a commercial scale only began in Australia a few years later, with mills established in Sydney in 1867 and Melbourne in 1868.[47]

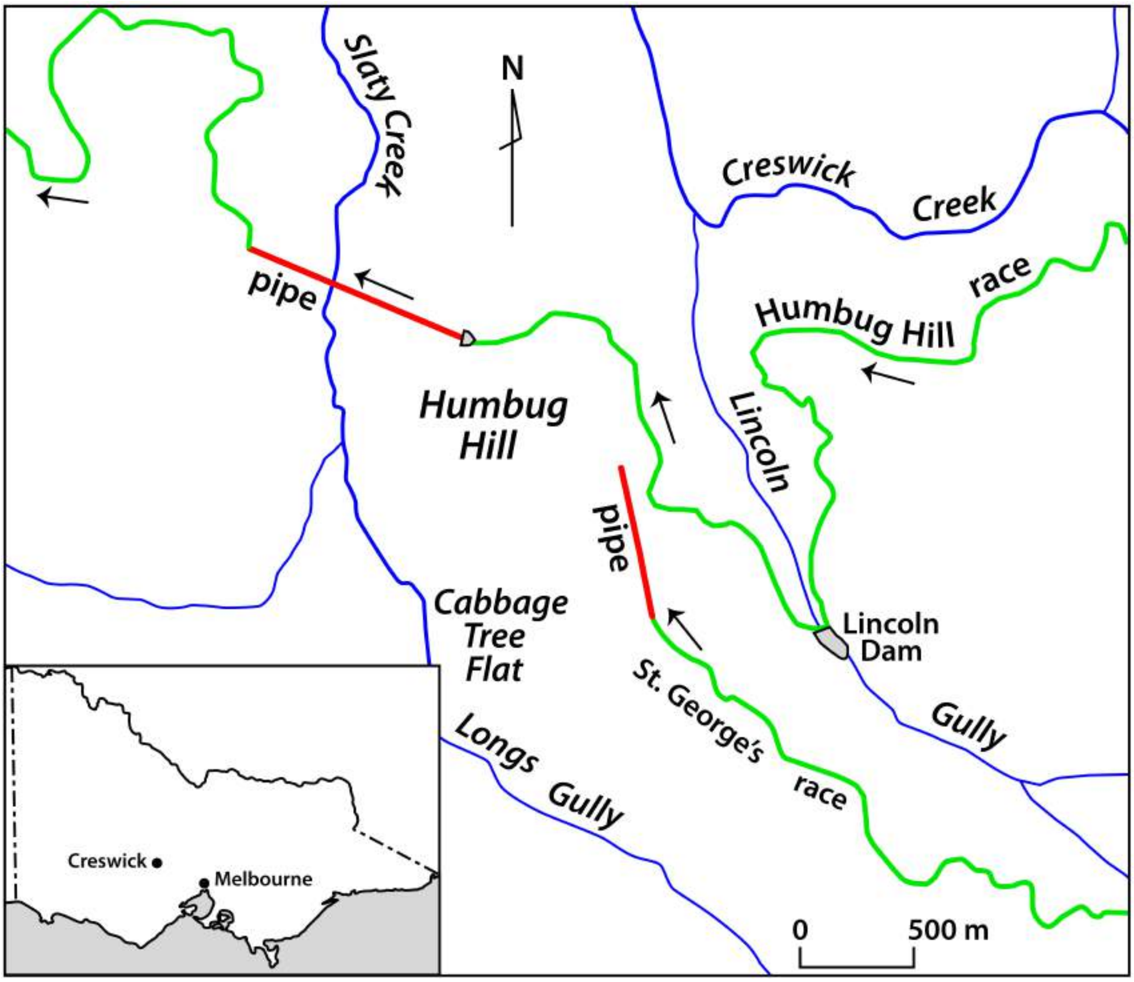
Bitumen pipes were also imported into Victoria in the early 1860s. While the Joske brothers' applications for patents to bitumen paper technology in 1860 had been unsuccessful, they soon became local agents for the Patent Bitumenized Water, Gas, and Drainage Pipe Company of London, which appears to have held the patent for the Newbold process.[48] The firm maintained an office at 2 Little Collins-Street West in Melbourne and received several shipments from London, including 74 cases of bituminized pipes in December 1861.[49]

By 1861 bitumen paper pipes were being used in various contexts for water supply, drainage and gas distribution. They were laid in Flinders Street in Melbourne to distribute water from the Yan Yean metropolitan system, while others had been shipped to South Australia and Tasmania for water supply purposes.[50] The municipal council in the goldfields town of Ararat in western Victoria also installed bitumen pipes to carry the town's water supply.[51]

On the goldfields, it was reported that a section of 9-inch (23 cm) bitumen pipe had been used successfully used for at least 18 months by the Johnson's Reef Gold Mines Company of Bendigo for pumping to their claim.[52] In 1862 the Pleasant Creek Quartz Mining Company at Ararat used bituminized pipes to convey water for 400 feet (122 m) from a dam to a steam engine.[53] It was on the Creswick goldfield, however, that bitumen pipes appear to have been taken up most eagerly, with two alluvial mining companies investing substantial sums in the new technology.

One of the most prominent groups to work alluvial deposits at Creswick was the Humbug Hill Sluicing Company, which began operations around 1856 under the management of Irish-American John Boadle Bragg. The party built a large earthen dam on a tributary of Creswick Creek, which delivered water along 11 kilometres of race to the Company's claim on the slopes of Humbug Hill. In 1860 the partners sought to extend the race a further 10 kilometres to the west, intending to divert water to mining claims along the way. The main obstacle to completing the Company's water system, however, was Slaty Creek, where the broad creek flats were more than 20 metres below the group's lowest operation on Humbug Hill. Almost half a mile (804 m) of fluming or piping was needed to convey the water across by gravity at sufficient pressure.[54]

Figure 2: *Creswick alluvial goldfield and location of paper bitumen pipes*:



Source: Peter Davies.

In 1862 the Humbug partners commissioned the PBPC to lay 750 yards (686 m) of eight-inch (203 mm) internal-diameter pipes across Slaty Creek. The pipeline was used instead of an open flume and was constructed as an inverted siphon carried partly on low timber trestles. The pipe began in a small header dam on the hillside about 114 feet (34m) above the height of the creek. It descended into the valley and rose to discharge the water into an open race on the other side. Water flowed through the pipes for the first time on 10 September 1862 in 'the greatest practical test that paper pipes have been put to on any of the gold-fields'.[55] About 50 people were on hand to observe the occasion, and the initial success was announced with the firing of a gun. The bitumen pipes cost a total of £650 to install.[56]

The St. George's Sluicing Company also established a bitumen pipeline in 1862, in the same area and at the same time as the Humbug Hill Sluicing Company. A group was originally established in 1857 by Canadian miner James William Robertson, who employed mostly Chinese workers to construct a 14-mile (22 km) race to bring water to Humbug Hill.[57] The terminal section of the race ended in a wooden flume that carried water from Lincoln Hill across a shallow saddle to the mining claim. Robertson sold his mining and water interests in 1861 before joining the gold rush in New Zealand, and the enterprise then became known as the St. George's Sluicing Company.[58] New partners in the group soon replaced the wooden flume with bitumen paper pipes, commissioning the PBPC to lay 560 yards (512m) of 'No.2' six-inch (152mm) bore pipes with 'light iron joints', at a cost of £500.[59] Water flowed through the pipes on 15 September 1862, only five days after the same feat was achieved by the Humbug Hill Sluicing Company.[60]

End of a dream

If the advantages of bitumen pipes were their cost and light weight, the disadvantages in performance and durability soon became all too apparent. Ararat miners and municipal officers began to question the durability of the pipes almost immediately, with problems reported in January 1863, only a few months after the installation of the pipes. The Pleasant Creek Quartz Mining Company found that the bitumen peeled off and blocked the feeder pipes and then the weakened pipe itself began to collapse. The company responded by replacing bitumen with iron pipes, and indicated that they were willing to give the bitumen pipes away to anyone who would take the 'much vaunted and highly-praised-up paper swindles'.[61] At the same time there were problems with the town's water supply pipes, which continued to leak despite 'all the tinkering and tar daubing that has taken place about their joints'.[62]

The bitumen pipes were advertised as withstanding pressure up to 400 lb per square inch, or more than 2750 kilopascal.[63] Once in use in actual mining situations, however, those results were seldom achieved and the new pipes quickly began to leak. After only two weeks in use, the pipes in the inverted siphon of the Humbug Hill Sluicing Company at Creswick had burst at the lowest level from the pressure of water.[64] Repairs to the system were soon made but within two years the Humbug party was sufficiently dissatisfied, and decided to replace the faulty bitumen pipes with seven-inch (18cm) iron pipes. The partners were reported to have 'suffered very considerable loss of both money and time' in using the bitumen pipes.[65] They contracted with the Melbourne ironworks of Cairns, Wilson and Amos to undertake the work, which was completed in September 1864. Leaking pipes also presented problems for the neighbouring St. George's Sluicing Company, being a 'source of annoyance and loss' to the partners.[66] However, by early November 1862 the pipes were reported to be in good condition and carrying water well, after repairs had been carried out on an earlier rupture.[67]

Engineers for the PBPC had previously recognised that joints between pipes were a potential weakness, especially when carrying water under pressure. In response, Mr James Pullen, who was responsible for the plumbing and jointing work of the company, developed two socket technologies. The first of these used a tin ferrule to cover a slip joint between the pipes, which was then filled and covered with melted bitumen. The other process used a washer of India rubber placed between square iron flanges which were then bolted together.[68]

Other manufacturing processes tackled the issue of joint weakness differently. Newbold's patent, for example, described the formation of several types of sockets and pipe joints. Ordinary sockets were made by rolling an extra length of bituminized paper around a short cylinder mounted at one end of the pipe mandril, thereby creating the socket as part of the pipe. Coiling lengths of wire onto the ends of the tubes during manufacture made screw threads. Newbold's design avoided conventional square flanges with the use of a narrow collar at the end of each pipe, with nuts and bolts or cotter pins used to join the pipe ends. For pipes facing considerable internal pressure, coils of wire were added to the exterior of the pipe during the manufacturing process. T and L pieces could also be constructed with narrow strips of paper cut to the required width and wound at the appropriate angles to form the shape required.[69]

As failure after failure demonstrated, neither Newbold's solution nor that of the PBPC engineers was effective. Further orders ceased and the PBPC closed early in 1863, shortly after a London bank recorded that the partnership had a debit of £200,000.[70] Notices for the PBPC first appeared in *Sands and Kenny's Melbourne Directory* in 1861 but they had disappeared by 1864 and were not seen again. The company had been quick to seize on the advantages of the new technology and was successful at promoting its products widely in newspapers and professional journals to secure publicity and orders. Neither of the two directors, however, had relevant mining or engineering expertise and neither appear to have been involved in the day-to-day running of the company, their contribution largely being investment capital and their public standing.[71] The daily operation and technological competence of the company was in the hands of the manager, H.A. Dalton and the engineer, Frederic Moore, who were also on hand to supervise the installation of pipes on the Creswick goldfield.

With the closure of the PBPC, customers were left to make their own arrangements regarding repairs and removals. Some, apparently, were able to maintain the pipes in sufficient condition to continue to use them, with the St. George's Sluicing Company still using the pipes two years after installation.[72] How much longer the pipes lasted is not known and it is uncertain if they survived until 1879 when the local council gained control of the company's water right. Other companies, such as the Pleasant Creek Quartz Mining Company in Ararat, immediately replaced their pipes with iron.[73]

Traces of the discarded process have survived in the forest south of Creswick where the Humbug Hill Sluicing Company had its operations. The route of the bitumen pipe on the west side of Slaty Creek can still be clearly seen on the ground as a straight, narrow gap in the forest vegetation extending almost 200 metres through the bush. The line through the forest canopy and the depression in the undergrowth are the result of patches of bitumen that have remained on the ground, continuing to inhibit plant growth nearly 150 years later. It appears that the Humbug Hill Sluicing Company had no further use for the pipes, like the Ararat company that offered to give away the unwanted pipes. The Humbug Hill Sluicing Company treated their £650 investment as so much rubbish and left the pipes where they lay when the iron pipes were installed. Over time the paper decayed and bushfires melted the bitumen into pools including one evident in a modern bush track that now crosses the line of the siphon.

At some stage the pipes used by the St. George's Sluicing Company were also replaced. There is no archaeological evidence of them still in the forest, but a well-preserved section of pipe from this system was salvaged at some time and is now on display in the Creswick Museum. The pipe is 4 feet 4 inches (1.33m) long with a thickness of 7/8 inch (22mm) and an internal diameter of 6 inches (15cm). The wall of the pipe consists of about 50 overlapping layers of bitumen-impregnated paper but no sign of the joints used to connect the pipe have been identified. The exterior of the pipe is coated with sand, which indicates it was probably produced at the Flemington factory of the PBPC. The pipe has collapsed all along its length and is bent in the middle although it is not clear if this damage occurred while the pipe was in use or after its abandonment in the forest. The surviving section of pipe provides further evidence regarding the failure of the technology. The internal lining was intended by the manufacturers to be as smooth as cast iron pipes but was instead lumpy and uneven. This irregularity increased the friction of water in contact with the interior of the pipe, causing greater turbulence within the column of water. This may have contributed to increased pressure at certain points and a greater likelihood of leaks.

Figure 3: *Bitumen pipe in Creswick Museum*

Discussion

The failure of the bitumen pipes was not fatal for the Creswick companies. Both the Humbug Hill Sluicing Company and the St. Georges Sluicing Company continued operations for many more years until their water networks were taken over by Creswick Council around 1880.[74] Mining returns and the sale of their water were so lucrative that the companies were able to absorb the costs of the failure of the pipes. Both companies had been willing to invest in and experiment with new technology, and they were able to do so without jeopardising their long-term success. That the companies were willing to take such a risk on untried technology and to accept the result reveals much about prevailing attitudes in the mining industry and more broadly, about the social and economic context of technology transfer.

Gold miners were constantly faced with the challenge of finding solutions to problems outside their previous experience. They could be creative in adapting and combining existing skills, as when two California miners, one formerly a sail maker and one a tin-smith, worked together to produce the combined hose and nozzle used in hydraulic sluicing.[75] They were also open to borrowing new technologies that appeared to solve the problem at hand. In the words of Peter Bell, they were ‘amateurs … borrowing labour saving-devices … when they could but not hesitate to make their technology up as they went along’.[76]

Social factors like the openness of the Victorian mining community play an important role in technology transfer. Anthropologists studying the process of adopting new technology have observed that any given technical problem will have several potential solutions and the final choice will have as much or more to do with social conditions than with technical constraints.[77] The experience and prior knowledge of those deciding, the perceived status of the alternative solutions, and the ease of fit between the new technology and the existing system are all important though often unconscious influences. Once the decision has been made and must be explained, technical factors are cited and indeed often appear inevitable, but this only seems to be the case in retrospect.

From this perspective it appears that the prestige of the directors of the PBPC and the aggressive publicity campaign they were able to mount may also have contributed to the widespread and rapid installation of the bitumen pipes. The cost advantage of the product could be evaluated independently but technical comparability could only be determined over time and on the advice of those who seemed to be in a position to know. The company was able to use trial results and recognition by a major scientific exhibition to bolster their claims regarding the product, and willing customers relied on this evidence to their detriment.

Ultimately the PBPC paid more dearly for the failures than did the miners, as the manufacturing company collapsed, while the mining companies continued. Pragmatically, the miners rectified their mistake as quickly and cheaply as possible. While willing to invest in something new they had no long-term advantage in spending good money after bad by persisting with the bitumen pipes and trying to make them work. Instead the miners began replacing the pipes immediately the problems were identified and, as the archaeological evidence demonstrates, abandoned the pipes where they lay, there being no prospect of salvaging materials or finding other purchasers.

The innovation that characterised Victorian mining in the first decade after the gold rush ultimately led to a long-lived and successful Australian mining sector, producing skills and technologies used around Australia, and exported to foreign mining fields.[78] It was not, however, a straightforward or linear process. Technical development proceeds by trial and error and for every much-publicised success there were many failures. In hindsight it seems clear that the bitumen pipes would be too weak for the pressures faced but this was not obvious at the time, and it was only because some entrepreneurs were prepared to take both financial and technological risks that the industry as a whole was able to advance.

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[19] *The Argus*, 2 January 1861, p. 7b.

[20] *Ibid.*, 20 August 1860, p. 6d.

[21] C. Newbold, 'Specification for "Invention for Manufacturing Vessels and other Articles and the Machinery & Apparatus to be employed therein"', Patent No. 353, Colonial Secretary's Office, 9 July 1860, manuscript held by State Library of Victoria, Melbourne.

[22] R.L. Hills, *Papermaking in Britain 1488-1988*, The Athlone Press, London, 1988, p. 125.

[23] C. Mayes, *The Australian Builders' Price Book*, Sands and McDougall, Melbourne, 1862, p. 112.

[24] The Fourdrinier paper machine was invented in France in 1799 by Nicholas Louis Robert. It consisted of a moving an endless belt of wire that received a mixture of pulp and water, revolving so as to allow excess water to drain away. This resulted in a continuous sheet that was dried by heat and pressure, with rollers or plates smoothing the paper to the desired finish. R.W. Sindall, *The Manufacture of Paper*, Archibald Constable & Co., London, 1908.

[25] D. Hunter, *Papermaking: The History and Technique of an Ancient Craft*, second edition, Alfred A. Knopf, New York, 1957, pp. 374-381; J.A. McGaw, *Most Wonderful Machine: Mechanization and Social Change in Berkshire Paper Making, 1801-1885*, Princeton University Press, Princeton, New Jersey, 1987, pp. 189-206. A related pipe technology from this period was fibre drain or 'Orangeburg' pipes, made from layers of wood pulp and bitumen pressed together. The pipes were developed in the United States in the 1860s and were widely used until the 1970s. www.sewerhistory.org/articles/compon/orangeburg, accessed 23 July 2014; H.E. Babbitt, J.J. Doland and J.L Cleasby, *Water Supply Engineering McGraw-Hill Book Company*, sixth edition, New York, 1967, p. 215.

[26] *The Argus*, 4 September 1861, p. 7d.

[27] The Caribbean island of Trinidad features a large, naturally occurring lake of asphalt that has been exploited for centuries. The lake covers about 115 acres (46 hectares), and during the nineteenth century asphalt was loaded into small rail cars and hauled by cable to a pier for loading onto ships. A subterranean layer of oil sands beneath the lake carries asphaltic petroleum and natural gas under high pressure, which comes into contact with clay and silica and is converted into asphalt near the surface. H. Abraham, *Asphalts and Allied Substances*, third edition, Crosby Lockwood and Son, London, 1929, pp. 129-134.

[28] Newbold, Specification for Patent No. 353, 1860.

[29] M. Churchward, 'Bendigo Foundries and Engineering Works', in M. Butcher and Y.M.J. Collins (eds.), *Bendigo at Work: An Industrial History*, Holland House for National Trust of Australia (Victoria), Strathdale, Vic., 2005, pp. 33-54; N. Ioannou, *Ceramics in South Australia 1836-1986: From Folk to Studio Pottery*, Wakefield Press, Adelaide, 1986, p. 6.

[30] M. Lewis, *Australian Building: A cultural investigation*, www.mileslewis.net/australian_building retrieved 4 July 2012, section 9.04.20.

[31] A. Both, 'From Plants and Miners Hats to Magnetic Exploders: Gutta percha in the service of miners', *Journal of Australasian Mining History*, vol. 9, 2011, pp. 143-155.

[32] W. Davidson, *Wrought Iron Water Pipes*, J.C. Stephens, Melbourne, 1887.

[33] A. Sutherland, *Victoria and Its Metropolis: Past and Present*, vol. II, McCarron, Bird & Co, Melbourne, 1888, p. 25.

[34] Mayes, *Australian Builders' Price Book*, pp. 99, 103.

[35] *Dicker's Mining Record and guide to the gold mines of Victoria*, February 1862, Thomas Dicker, Sandhurst, Victoria, p. 16; Mayes, *Australian Builders' Price Book*, p. 112.

[36] Chief Secretary, *Indexes to Patents Registered in Victoria 1854-1866*, Chief Secretary's Office, State Library of Victoria, Melbourne, p. 105; C. Mayes, 'Essay on the manufactures more immediately required for the economical development of the resources of the colony', in *The Victorian Government Prize Essays*, Government Printer, Melbourne, 1861, p. 346.

[37] Newbold, Specification for Patent No. 353, 1860.

[38] Chief Secretary, *Indexes to Patents*, pp. 105-106.

[39] Lewis, *Australian Building*, section 9.04.20.

[40] *Ovens and Murray Advertiser*, 17 November 1860, p. 1a; *Dicker's Mining Record*, February 1862, p. 16.

[41] *The Argus*, 4 September 1861, p. 7d.

[42] P. De Serville, *Port Phillip Gentlemen*, Oxford University Press, Melbourne, p. 174; K.A.R. Horn, 'Castella, Paul Frederic de (1827-1903)', in N.B. Nairn, A. G. Serle and R.B. Ward (eds.), *Australian Dictionary of Biography*, vol. 3, Melbourne University Press, Melbourne, 1969, pp. 367-368.

[43] W.H. Archer, F. Mueller, R.B. Smyth, Prof. Neumayer, F. McCoy, A.R.C. Selwyn and W. Birkmyre, *Catalogue of the Victorian Exhibition, 1861*, John Ferres, Government Printer, Melbourne, 1861, p. 297.

[44] *The Argus*, 4 June 1861, p. 8b.

[45] C. Mayes, *The Victorian Contractors' and Builders' Price-Book*, C. Mayes, Melbourne, 1859, p. 149.

[46] The mining of oil-shale deposits in New South Wales began in 1865, producing crude oil for refining into kerosene. The process created a variety of by-products including cleaning and preserving oils, but it is not clear if bitumen was produced as well. I. Jack, 'Joadja, New South Wales: The paragon of early oil-shale communities', *Australasian Historical Archaeology*, vol. 13, 1995, pp. 31-40; L. Knapman, *Joadja Creek: The Shale Oil Town & Its People 1870-1911*, Hale & Iremonger, Sydney, 1988, p. 136.

[47] E.K. Sinclair, *The Spreading Tree: A History of APM and Amcor*, Allen & Unwin, Sydney, 1990, pp. 11-17.
[48] *The Argus*, 3 October 1860, p. 8f; *Colonial Mining Journal*, vol. III, no. 2, October 1860, p. 18.
[49] *The Argus*, 19 June 1861, p. 3f; *ibid.,* 5 December 1861, p. 4a.
[50] *Ibid.,* 4 September 1861, p. 7d.
[51] *Ararat and Pleasant Creek Advertiser*, 20 January 1863, p. 2c.
[52] *The Ballarat Star*, 5 February 1862, p. 2e.
[53] *Ararat and Pleasant Creek Advertiser*, 27 January 1863, pp. 2-3.
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[55] *Creswick Advertiser*, 12 September 1862, p. 2b.
[56] *Ibid.*, 3 June 1862, p. 2d.
[57] G. Wynn, 'Life on the Goldfields of Victoria: Fifteen Letters', *Journal of the Royal Australian Historical Society*, vol. 64, no. 4, 1979, pp. 258-268.
[58] G.H. Scholefield, 'Robertson, James William', in *A Dictionary of New Zealand Biography*, vol. 2, Department of Internal Affairs, Wellington, 1940, pp. 246-247.
[59] St. George's Sluicing Company, 'Memorial', 18 September 1862, Box 30, E.J. Semmens Collection, University of Melbourne Archives.
[60] *Creswick Advertiser*, 16 September 1862, p. 2c.
[61] *Ararat and Pleasant Creek Advertiser*, 27 January 1863, pp. 2-3.
[62] *Ibid.*, 20 January 1863, p. 2.
[63] *Dicker's Mining Record*, February 1862, p. 16.
[64] *Creswick Advertiser*, 7 October 1862, p. 2d.
[65] *The Ballarat Star*, 5 September 1864, p. 3b.
[66] *Creswick Advertiser*, 24 October 1862, p. 2d.
[67] *Ibid.,* 11 November 1862, p. 2e.
[68] *The Argus*, 4 September 1861, p. 7d; *ibid.,* 7 September 1861, p. 5d.
[69] Newbold, Specification for Patent No. 353, 1860.
[70] De Castella, *Australian Squatters*, translation, with introduction and notes, by C.B. Thornton-Smith of *Les Squatters Australiens (1861)*, Melbourne University Press, Melbourne, 1987, p. 24.
[71] In the early 1860s Captain Anderson was busy reorganizing the Victorian Volunteer Force into a professional military service, while De Castella was preoccupied with establishing the family's large vineyard in the Yarra Valley east of Melbourne. B. Marmion, 'The Victorian Volunteer Force on the central Victorian Goldfields, 1858-1883', M.A. thesis, La Trobe University, 2003, p. 57; D. Dunstan, *Better Than Pommard! A History of Wine in Victoria*, Australian Scholarly Publishing and Museum of Victoria, Melbourne, 1994, pp. 84-87.
[72] *Creswick Advertiser*, 12 August 1864, p. 2; *Dicker's Mining Record*, October 1864, p. 180.
[73] *Ararat and Pleasant Creek Advertiser*, 27 January 1863, pp. 2-3.
[74] Davies, Lawrence and Turnbull, *Historical Archaeology of Water Management*, pp. 63, 77.
[75] P.R. May, *Origins of Hydraulic Mining in California*, Holmes Book Company, Oakland, California, 1970, pp. 40-46.
[76] P. Bell, *Gold, Iron and Steam: The Industrial Archaeology of the Palmer Goldfield*, James Cook University, Townsville, 1987, p. 115.
[77] P. Lemonnier, 'Introduction', in Pierre Lemonnier (ed.), *Technological Choices: Transformation in Material Cultures Since the Neolithic*, Routledge, London, 1993, pp. 1-35.
[78] Birrell, The Development of Mining Technology, p. 3.