ARCHAEOLOGY IN NEW ZEALAND

THE SERPENTINE WATER WHEEL AND BATTERY, CENTRAL OTAGO

An exercise in Industrial Archaeology

P.G. Petchey
Dunedin

INTRODUCTION

The water wheel and battery situated in Long Valley, near the old Serpentine Church, in Central Otago (Fig. 1) is one of the most complete waterwheel driven gold batteries remaining on the Otago goldfields, and the only one to have both the wheel and stamper battery surviving intact together. As such, it provides a rare opportunity to examine the theory of operation of such an installation from an archaeological perspective, where the physical remains can be used to assess other historical sources.

HISTORY

Turnbull's reef was opened in 1884 or 1885, with trial crushings supposedly yielding a rich 4 oz. to the ton (AJHR 1885 C2:12). However, due to flooding, work on the reef stopped when the shaft was only 40 feet deep. In late 1886 or early 1887 a new company, the Golden Gully Quartz-mining Company, was formed to re-open the reef (AJHR 1887 C5:38). A great deal of work was done opening out the claim, in the hope of relocating the rich stone found by Turnbull. Crushing was initially done at a number of nearby batteries, but in 1890 the company erected their own plant, relocating an existing battery from "the top of the hill" (AJHR 1890 C3:170). The history of this battery is not certain, but it appears that it began life at German Jacks in 1878, was moved to Deep Creek in 1882, being enlarged from five to ten stamps, and was finally purchased and moved by the Golden Gully Q.M.C. in 1890. The battery was manufactured by Kincaid and McQueen of Dunedin (Dunstan Times 26/4/1878; Knight 1985:9), so by association the water wheel may have been made by the same firm; however, it bears no maker's name.

The operation was not a success, and the company ceased operations in 1891, leaving the battery in working condition on the ground (AJHR 1906 C3:62). It remained reasonably intact in its shed for many years (see the Otago Witness, 10/3/1931), until the corrugated iron was removed about the time of the Second World War. Since then, the battery and wheel have continued to deteriorate slowly, being damaged by fire on at least one occasion. Recently, the site has been the object of some attention from the Department of Conservation, who are undertaking a stabilisation and restoration programme.

THE SITE

The site was visited twice by the present author as part of an M.A. research programme into the archaeology of water wheels in Otago, and has also been described by Hamel (1992:20). Because of the relatively intact and complete

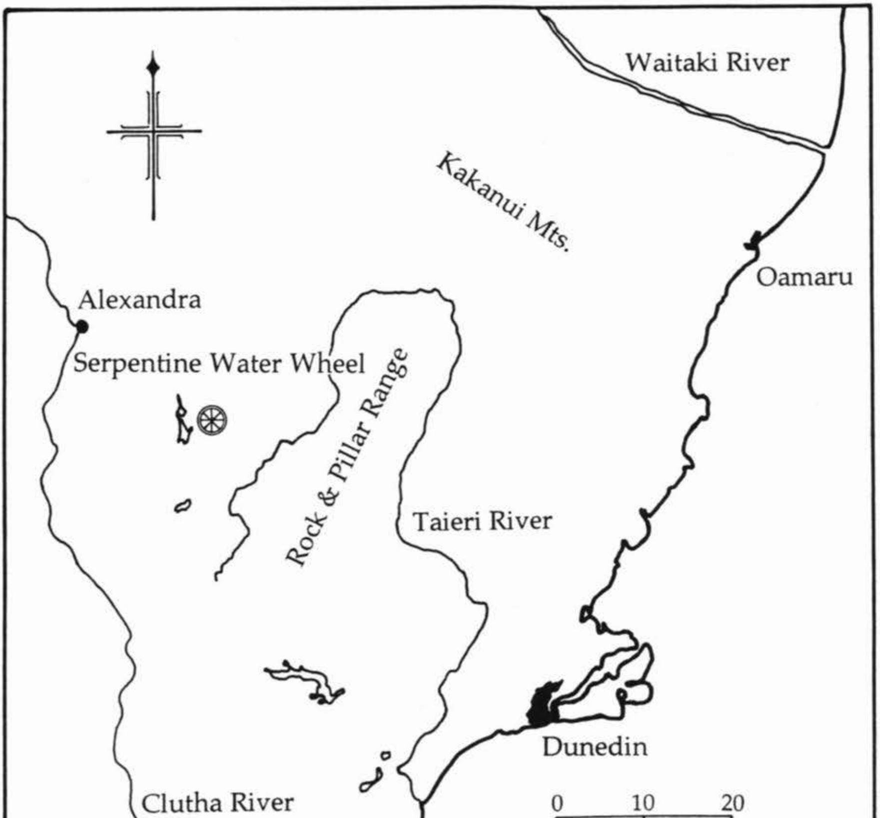

Figure 1. Location of Golden Gully Water Wheel, Serpentine.

Figure 2. Golden Gully water wheel, Serpentine.

state of the machinery, with the entire drive train surviving, it is the only remaining site in Otago where a number of historical sources regarding battery and water wheel operation can be tested archaeologically. The battery is located on the floor of Long Valley, at the base of the formation of an inclined tramway running down the valley side from the mine above.

The overshot water wheel is 26 feet in diameter, 4 feet wide (Fig. 2). It has timber spokes, a cast-iron hub, and an iron rim assembly (cast-iron shroud, wrought-iron buckets). The buckets are curved, a form adopted to increase efficiency of filling and emptying, and are ventilated. Ventilation was a feature formalised by the British engineer Sir William Fairbairn in 1828 (Fairbairn 1861:133), whereby each bucket has an air vent at the rear to allow air to escape while filling with water. This prevented blow-back on filling and suction on emptying, considerably increasing the efficiency of water wheels thus equipped.

The battery is a conventional ten-stamp mill, with two sets of five stampers driven from a single cam-shaft. On the end of the cam-shaft is a 30 tooth spur gear which engages a 240 tooth ring gear mounted on the side of the water wheel (Fig.3). There is no clutch, so there was a constant drive to the stampers, with a 1:8 gear ratio. To stop the mill, the water supply would have been shut off, and a brake applied to the wheel rim.

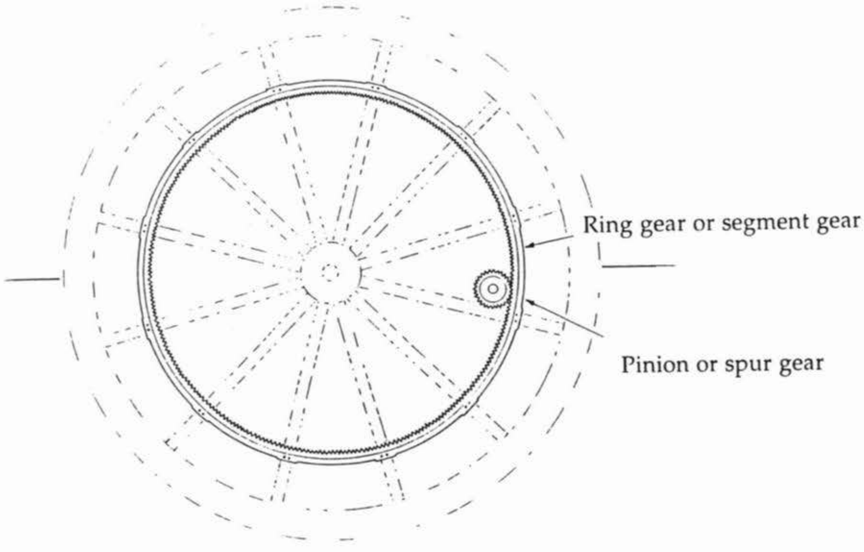

Figure 3. Ring gear drive.

OPERATION

Thus the site presents us with a number of measurable variables. As the water wheel was overshot with the water supply fed to the highest point, the fall of water equals the wheel diameter of 26 feet. The gear ratio between the wheel and camshaft is 1:8. As each cam has two lobes, each stamp is dropped twice for each camshaft revolution, or 16 times for each revolution of the water wheel. The drop of each stamp was about 10 inches.

A number of contemporary authors supplied data relating to water wheel and stamper battery operation. Those considered here are Fairbairn (1861), Gordon (1906) and Ulrich (1875).

Fairbairn (1861:138) suggested a rim velocity for high-breast and overshot wheels of between 4 and 6 feet per second, with a maximum of 7 feet per second for very well constructed wheels. Gordon (1906:317) provided the following table for the rim velocities of overshot and breastshot water wheels, which generally agrees with Fairbairn.

v = velocity of the periphery of the wheel in feet
h = the fall or head of water in feet

When	h = 5	V = 7.0 ft. per second
"	h = 10	V = 6.6 ft. "
"	h = 15	V = 6.2 ft. "
"	h = 20	V = 5.8 ft. "
"	h = 25	V = 5.4 ft. "
"	h = 30	V = 5.0 ft. "
"	h = 35	V = 4.6 ft. "
"	h = 40	V = 4.2 ft. "
"	h = 45	V = 3.8 ft. "
"	h = 50	V = 3.4 ft. "

This table suggests that the optimum rim velocity for the Serpentine water wheel would be 5.4 feet per second, which is inside the range suggested by Fairbairn. Gordon's theoretical velocities were then applied to the 26 feet diameter Serpentine water wheel, followed by the corresponding rates of work for the stampers, using the following formula;

π X diameter = circumference

circumference/velocity = seconds per revolution

60/seconds per revolution = revolutions per minute (water wheel)

water wheel revolutions X 8 = camshaft revolutions

camshaft revolutions X 2 = drops per stamp per minute

The results for Fairbairn's range of rim velocities of 4 to 6 feet per second and maximum of 7 feet per second, and Gordon's 5.4 feet per second were;

Rim velocity (ft.)	Water wheel revs. (RPM)	Drops per stamp per min.
4.0	2.94	47.01
5.4	3.97	63.47
6.0	4.41	70.52
7.0	5.14	82.27

This provides us with a range of battery operation speeds, based on contemporary water wheel velocity figures, applied to a surviving industrial structure. The intact fixed mechanical gearing of the Serpentine battery allows these figures to be calculated exactly, unlike most other surviving batteries which were often belt driven and/or are missing portions of their drivetrains. These figures can then be tested against various contemporary recommended stamper battery speeds. Gordon (1906:384) gave the following table of ideal stamper drop rates, the rate depending on the distance the stamps were dropped;

4 inch drop:	118.3	drops per minute
5 in. "	110.5	"
6 in. "	104.8	"
7 in. "	99.8	"
8 in. "	95.3	"
9 in. "	91.5	"
10 in. "	88.2	"
11 in. "	85.3	"
12 in. "	82.0	"

Ulrich (1875:35) gave slightly different figures for battery operation, based on his Victorian (Australian) experience. He suggested that the stamp drop should not be less than 7 inches, and that a drop rate of between 75 to 80 drops per stamp per minute was ideal. This is obviously somewhat removed from Gordon's recommendations. As the Serpentine battery was probably manufactured in 1878 (Dunstan Times 26/4/ 1878: AJHR 1879 H11;22), Ulrich's 1875 figures may be more applicable to the machinery than Gordon's faster figures of nearly thirty years later. Both sets of recommendations are discussed below.

As the Serpentine battery had a drop of about 10 inches, the optimum operation speed according to Gordon would be 88.2 drops per stamp per minute. However, examination of the projected operating rates based on water wheel speeds above, shows that this rate of operation was probably not obtained by the Serpentine battery with its present gearing. A drop rate of 88.2 per minute would require the water wheel to revolve at 5.51 R.P.M., with a rim velocity of 7.50 feet per second. At this velocity the buckets would probably not have filled properly and may have thrown water out, and the balance of the wheel would have to have been precise to avoid severe vibration. For Ulrich's minimum recommended speed of 75 drops per minute, the water wheel would need to run at 4.69 R.P.M., with a rim velocity of 6.38 feet per second. While this is within the extreme range allowed for by Fairbairn, it is still much faster than Gordon's recommendations. It is therefore doubtful that it ran this fast, 4.5 R.P.M. probably being the maximum operating speed, with 4 R.P.M. the most likely rate.

So how was the machinery operating, and if it was not operating at the recommended operating speeds, what was the reason? As we know from the historical records, this battery had been moved at least twice during its working life, possibly a number of times more. The water wheel has Roman numerals marked on its joints to aid precise reassembly, indicating that some care was taken in its reconstruction on site and that it was therefore probably reasonably well balanced. However, it was undoubtably designed to run at a set ratio, as to change the gearing would require either a new ring gear or new spur gear or both, any of which would require the movement of either the water wheel or stampers, to accommodate the change of physical size of the gears.

Therefore, the battery was set up to run within a range of set speeds, with the maximum operating speed restricted by the capabilities of the water wheel. The wheel's iron construction would have assisted its balance, as it would not have been prone to waterlogging as timber wheels were, and it would have had a flywheel effect providing a smooth and constant power delivery. As discussed above, it must be assumed that it was running at about the speed recommended by Gordon and Fairbairn, about 4 to 4.5 R.P.M., producing from 64 to 72 drops per stamp per minute at the battery. This would have been much slower than the rates given by Gordon, and closer but still slower than the slowest speed recommended by Ulrich. This poses no real problem, as it is always possible for machinery to run slower than the optimum speed, but dangerous for it to run more rapidly. Additionally, slower operation allows more leeway in balancing, and reduces general stresses on the plant structure.

The Serpentine battery was therefore almost certainly running below its potential (for both Gordon's and Ulrich's figures) while the water wheel was probably running at about its optimum speed. There is a wide range of possibilities that may account for this, some easier than others to assess one hundred years after the plant ceased working, such as the power output of the wheel, the water supply, the nature of the stone to be crushed, or maybe simply the availability of the machinery close to the site rather than its suitability or compatibility. There is no firm evidence that the water wheel and battery were initially designed to run together, rather than simply being combined on this site. More research into the history of the Golden Gully Q.M.C. could shed some light, but many of the records of these small gold mines have long since been lost, making such work difficult.

This is a field with the potential for more work, as there are several batteries that still have intact water turbines, and others with intact gearing but missing power source. Examination of remaining gearing and calculation of drive and operating speeds could be a useful tool for interpreting what type of power was used at a site even if no evidence of the power source itself remains.

CONCLUSIONS

The intention of this paper was to combine archaeological and historical information, to attempt to tell more about each. While we can easily go and see the Serpentine Battery, a purely archaeological approach does not explain how fast the wheel turned or how fast the battery ran or why the gearing used was chosen. Likewise, examination of the historical sources such as Fairbairn or Gordon tells us what was seen as the ideal operation of machinery by engineers, but does not tell us what was actually used in the field. Even contemporary descriptions of working gold batteries generally only give very brief details of machinery used, often with no mention of operating speeds or conditions.

But taking the archaeological and historical sources together, each helps to interpret the other. In the case of the Serpentine Water Wheel and Battery, it seems that the wheel was probably run at about its optimum speed of 4 to 4.5 revolutions per minute, but that the stampers were run relatively slowly. The reality of operating a very second hand battery in the field was probably that ideal performance was not sought, merely adequate performance.

This is the great strength of historical archaeology; it can tell us more about the past than can either archaeology or history on their own. It combines sources, and in doing so adds to the body of knowledge of both. This paper is not meant to be a comprehensive or definitive study of the Serpentine Battery, but rather an example of how a combined approach can be used to not only relate the history of a site, but also interpret the operation and dynamics of that site.

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