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Watermills with Horizontal Wheels

by: Paul Wilson

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WATERMILLS

with

Horizontal Wheels

by

PAUL N. WILSON

No. 7

S.P.A.B.

6/-

THE WIND AND WATERMILL SECTION
of

The Society for the Protection of Ancient Buildings

The objects of the Wind and Watermill Section are:

1. To stimulate the interest of the public in the preservation of wind and watermills.
2. To provide technical advice on questions relating to the repair of wind and watermills.
3. To make a detailed survey of wind and watermills as a permanent record with historical data of all mills in this country.
4. To encourage the craft of country milling.
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- } by Rex Wailes, F.S.A., M.I.Mech.E.
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KENDAL:
TITUS WILSON & SON, LTD.

1960

FOREWORD

I settle down to the task of writing No. 7 in the series of booklets on watermills published by the Watermills Publications Committee of the Society for the Protection of Ancient Buildings with a sadness of heart which I will attempt to confine to this foreword. It should have been the work of Miss E. M. Gardner, O.B.E., M.A., the capable and zealous editor of numbers one to six. She was always particularly interested in watermills with horizontal wheels (or, as they are often described, "Horizontal Watermills"). During the summer of 1957 she tramped many miles in Shetland with her notebook and camera visiting the remains of mills still to be seen there and as a result she wrote a short article entitled "Milling in the Shetlands" which appeared in *Country Life*, 6 March, 1958.

Before her retirement Miss Gardner held a senior post in the Civil Service, and as soon as she had some spare time she devoted herself to the pleasant task of tracking down and photographing watermills. After much research she wrote number four in the series, "The Three Mills, Bromley by Bow", and without her energy and drive few, if any, of these booklets would have seen the light of day. She was a woman of great character, humour and charm. We started to plan this booklet at her cottage near Harlech in 1958, with the September rain driving across the sea and beating against the windows. It was agreed that we should pool our knowledge, and she would do the writing. On Boxing Day that year we met for the last time; we had both had a busy autumn, and had not made much progress. She was, however, full of enthusiasm about news she had received that "Shetland" mills might still be working in a remote valley in South Africa. Early in April 1959 she died suddenly after a minor operation about which she had joked lightheartedly. Now I proceed alone, knowing how much better this work would have been had she written it.

PAUL N. WILSON

This book is dedicated to the memory
of

MISS E. M. GARDNER, O.B.E., M.A.,
not only for her services as Chairman of the
Watermill Publications Committee, and to the
Committee of the Wind and Watermill Section
of the S.P.A.B. (1951-1959), but for her
valuable contribution to the recording of
watermills in this country, and the infectious
enthusiasm and energy with which she
undertook this important work.

INTRODUCTION

"The water mill of Shetland exhibits a curious example of the survival to our own day of a piece of mechanism, connected with an essential industry of life, of a type so archaic as to be almost wholly unknown beyond its own immediate area, and to be scarcely recognisable by comparison with anything now to be found elsewhere in Britain. And yet, as we shall see, there is reason to believe that this primitive machinery, and such primitive structures as those within which this machinery is still worked in Shetland, were once common, if not universal, in this country, as was the case in Ireland and in the northern parts of the Continent of Europe and elsewhere . . . it will only be when they have become things of the past, as they are already showing symptoms of becoming, that their uniqueness will be recognised, and details regarding them will be prized."¹

With these words, in 1885, Gilbert Goudie opened the paper "On the Horizontal Water Mills of Shetland" which he presented in Edinburgh to the Society of Antiquaries of Scotland. It was a pioneer treatise, and has served as a useful background to many later authors. Probably even Goudie did not realise how soon these mills would ". . . become things of the past", or what an extensive field for research they were to provide for future archaeologists.

This brings me to my main difficulty in writing the booklet. The general subject of "Horizontal Watermills" has already been extensively covered from several aspects. In 1856 Robert MacAdam of Belfast wrote a short paper entitled "Ancient Watermills"² dealing primarily with the Moycraig wheel (to which further reference will be made), but, like Goudie, referring also to the use of the mill in other parts of the world. In 1899 Bennett and Elton published their remarkable "History of Corn Milling"³ and devoted some 24 pages to the subject, including many sketches and illustrations. Much that has been written since is based upon their work, and their references are frequently quoted. Equally informative is E. Cecil Curwen's article published in 1944 in "Antiquity", "The Problem of Early Watermills".⁴ This is largely devoted to horizontal mills, and advances a theory that they spread from the middle East (or possibly China) to the west and north of Europe. More specialised, but still containing much general information about the mills, are the articles by Lucas in 1953⁵ and Fahy in 1956⁶ dealing with the discovery of remains of mills in Eire and giving information about the probable date of their introduction into that country.

Miss Gardner and I discussed how we could produce a booklet which would be interesting, but not just an anthology of other people's work. Some readers will know little or nothing of the

general history of horizontal mills as set out clearly by Bennett and Elton and Curwen; others will shrink at the thought of wading through "all that old stuff again!" On the whole, I think that the only thing to do is to try and compromise. I will deal with the history as concisely as possible, but devote a little more space than others have done to the types of wheel, the two basically different methods of conveying water to it, and its use in countries which have not generally had very much mention in works published in Great Britain. Finally, I have tried to introduce a little originality into the illustrations.

This booklet cannot be regarded as a learned treatise; if it interests the casual reader and influences the few to seek further information from the bibliography provided, I will be satisfied.



MISS E. M. GARDNER.



The 'Foot' of a Shetland Mill

Three Shetland Mills



Plate 1.

From photographs by Miss E. M. Gordon published in Country Life, 9 March, 1938.

THE WATERMILL WITH A HORIZONTAL WHEEL

Most readers will be familiar with the ordinary "vertical" water-wheel with its horizontal shaft and drive through right-angle gearing to the millstones. It is, unfortunately, rapidly disappearing, but there are still many to be seen either working or derelict, and there are thousands of pictures of them in art galleries, books and postcards throughout the western world. They vary in power from the tiny wheels in the Swiss Alps, used to turn butter churns, to the huge industrial wheels of the nineteenth century, some of which developed over two hundred horsepower. Even in the Middle Ages the majority of these mills which, with their wheels ten or even twenty feet in diameter, were not cheap to build, were the important prime-movers used by a slowly developing capitalist society. Fitzherbert puts the case for their erection concisely:

"Also upon these waters, the lorde may set divers maner of mylnes the which maye be to the Lordes great ease and profit."⁷

The horizontal mill, in its simplest form, (and these are the mills with which we are mainly concerned) is quite different. It is essentially the simple tool of a primitive agricultural community, and is a natural development of the quern turned by water instead of by hand.

It is made almost entirely of wood, and comprises a boss into which are morticed a number of blades or paddles, the shape of which varies in different countries. The shaft, which may be of wood or iron, is vertical, and the wheel rotates in a horizontal plane. Below the wheel there is a pivot bearing which is often fixed in a beam which can be raised or lowered slightly so as to adjust the gap between the millstones. The only other bearing is a simple bush, usually located in the centre of the lower millstone. The upper stone rotates with the shaft (there is no gearing), the simplest method of drive being by means of a short piece of iron (in England called the "Rynd" and in Shetland the "Sile") which is let into the "eye" or central hole in the stone and fits loosely over a square on the top of the shaft. (See Fig. 1.) Thus it hangs freely, and when rotating takes up a natural position giving an even gap between the two stones. A square hopper, like an inverted pyramid, is secured above the upper stone and the grain drops into the "eye" from a spout which is continuously joggled by a "clapper" resting loosely on the upper stone and connected to the spout by a string or a stick. A wooden trough, inclined at an angle of from 20° to 40° to the horizontal, carries water diverted from a stream to a point near the outer radius of the wheel. Pouring out of the end of the trough the water strikes the blades and

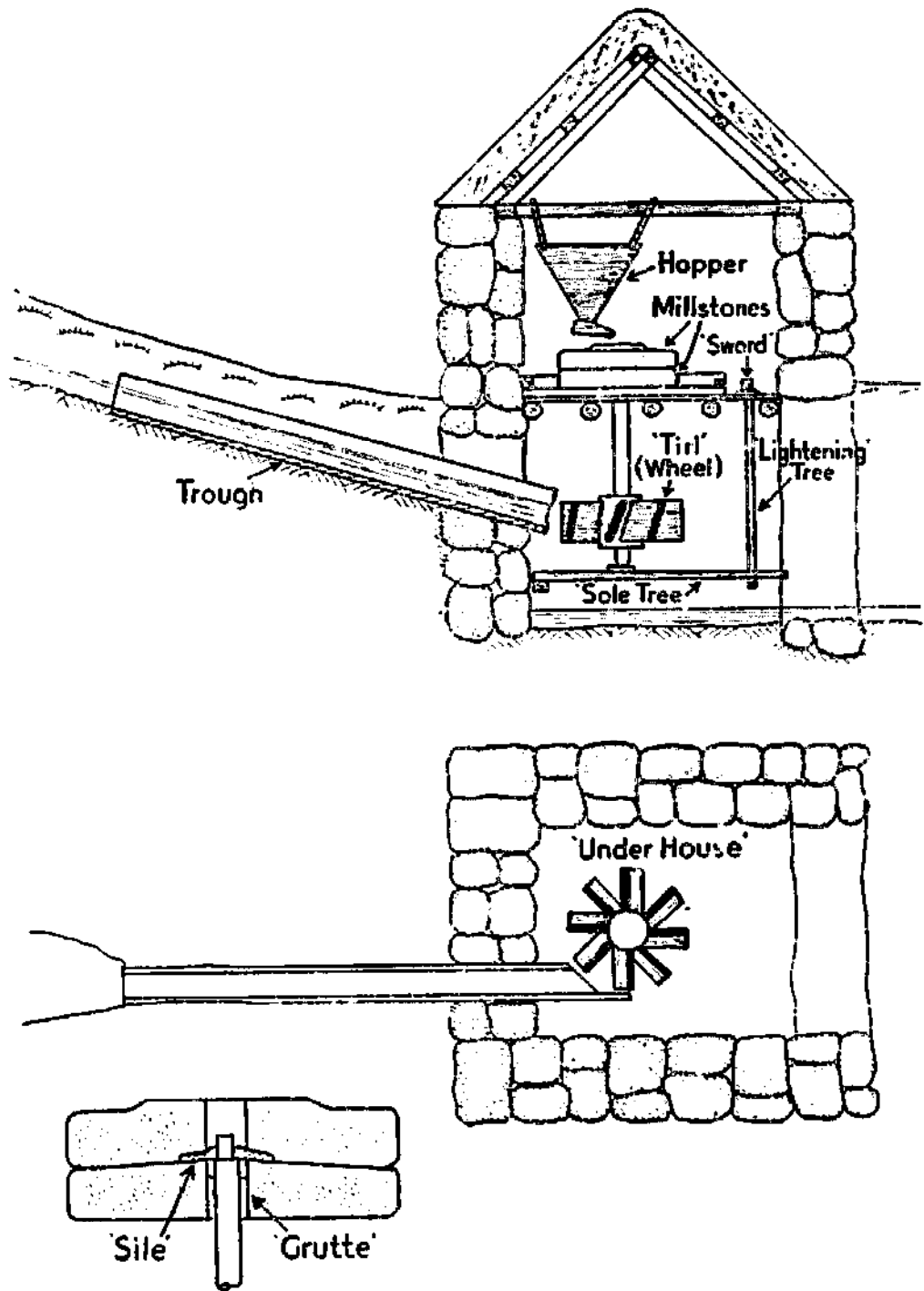


Fig. 1.
Shetland Mill.
Breckon Loch, Eshaness.

Drawing based upon a sketch by H. W. Dickinson and E. Straker, 1932.
Transactions of the Newcomen Society Vol. XIII, 1932-1933.

so turns the wheel and the upper stone. The whole machine is mounted in a small building of local stone or timber, the wheel being situated in the lower house and the millstones and hopper in the upper. (The South African mill shown in Plate 6 is unusual if not unique in that there is no upper house.) Fig. 1 shows a typical Shetland mill, and Plate 1 a wheel and mill buildings.⁵

There is not very much scope for variety in the design and arrangement of the upper house: the maximum of difference can probably be observed by comparing the crude simplicity of the mill in Gamkas Kloof, Plate 6, with the sophisticated lay-out of the Italian alpine mill shown in Plate 2. Even so, basically they are the same.

In the design and construction of the wheels there is very much more local variation, and in Fig. 2, "1" to "6", I have tried to sketch, approximately to the same scale, six types of wheel which show the commonest designs, excluding China. I have named the six with some hesitation, and in the light of such information as I have available. The following descriptions should be read with the sketches.

1. SHETLAND — NORSE (OPEN)

This is the simplest type of wheel with relatively few blades (4 to 12) and no shrouding. The blades are flat, and may be set at an angle, as shown, bringing them approximately at right angles to the line of the trough, or vertical, i.e. parallel to the shaft. These wheels are typical of the Scottish Islands, Scandinavia, Faroes, South Africa, etc. In the Scottish Islands, where there is no indigenous timber, they were usually made of driftwood or old packing-cases. The drawing is based on Dickinson and Straker and numerous photographs.

2. SHETLAND — NORSE (SHROUDED) (Shroud is a term used to describe a rim surrounding the extremities of the blades)

The shrouded wheel usually has a greater number of blades (Jespersen has a photograph of one in Norway with 20) and a larger diameter boss. The shroud is of iron or thin wood; it strengthens the wheel, reduces the danger of damage to the blade ends, and probably tends to raise efficiency by reducing the loss of water due to splash. The distribution is as for "1".

3. IRISH

This drawing is taken approximately from the Moycraig wheel in the Belfast Museum. Most of the Irish mills appear to have had "spoon" shaped blades. These were an improvement upon the flat Shetland paddles, and were probably carved from local timber. A relatively small jet of water was directed through a hole in the end of the trough and would strike the deepest

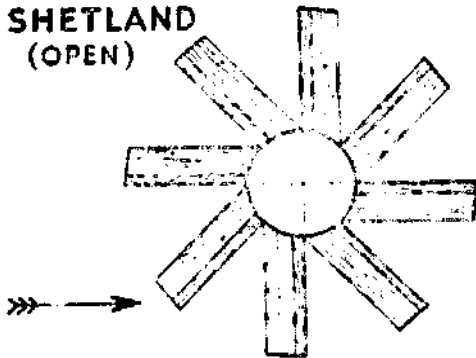
Direction of jet.

All wheels are viewed from above and are shown to be rotating counter-clockwise.

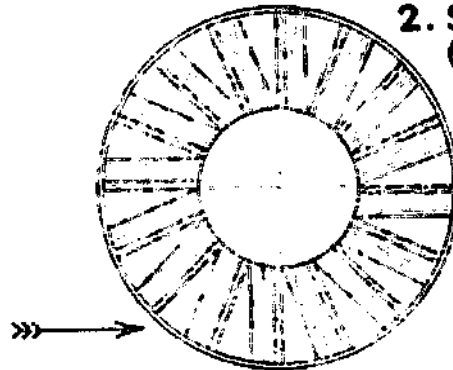
Shows where elevations and sections are taken.



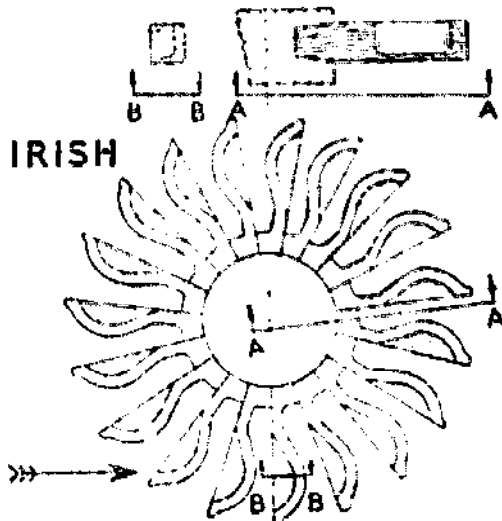
1. SHETLAND (OPEN)



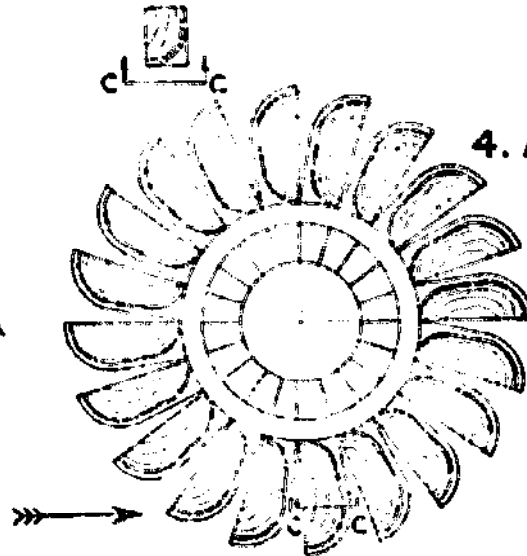
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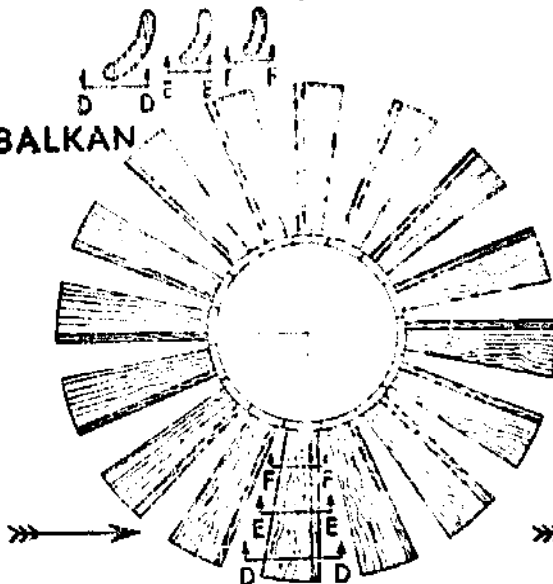
3. IRISH



4. ALPINE



5. BALKAN



6. ISRAEL

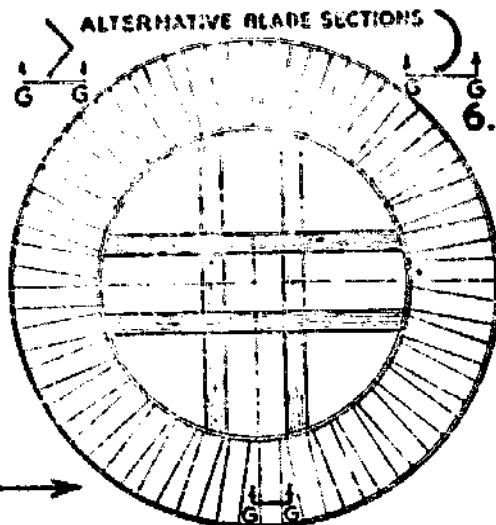


Fig. 2.

Typical Horizontal Mill Wheels .

section of the "spoon". Both the design and construction indicate a high degree of craftsmanship. Wheels with blades of this type are described by a number of authors as having been observed from the Hebrides to as far south as Portugal.

4. ALPINE

Wheels of this type possibly extend from the Alps to the Pyrenees or further. The drawing is taken from a wheel in the Museo Nazionale Della Scienza Tecnica Leonardo da Vinci, Milan, reproduced in Plate 2. There is a very similar mill in the Deutches Museum, Munich. Note the deep buckets hollowed out of solid timber which will have quite a good efficiency. They are, in fact, surprisingly like half the bucket of a modern "Pelton Wheel".

5. BALKAN

This drawing is based upon a sketch made by Dr. Gilbert Wilson of the Imperial College of Science and Technology, London, when prospecting for minerals in Jugo Slavia in 1928. He speaks of mills with wheels of this type being common in the area over which he was working. The wheel is similar to "1", but the blades are longer and are curved to give improved efficiency. Goudie includes a sketch of the wheel of a mill in Persia (c. 1880) 4 ft. 6 ins. in diameter with 26 blades almost exactly like those shown except that they have a flat instead of a curved cross section.⁹

6. ISRAELI

Shemuel Avitsur has supplied several photographs of Israeli wheels which have worked within the last decade. Except for the wooden clasp-arms they are of sheet iron construction. Usually the vanes are bent at an angle of about 90°, but sometimes they are semi-circular in section. Relatively the diameter is greater than that of the other wheels.¹⁰

The other important point of difference in the design of the mills is the way in which the water is conducted to the wheel. The simple, open trough, sometimes tapering towards the bottom to give a more concentrated jet, is usually applied to the more primitive wheels, particularly if there is ample water. Fig. 1 and Plate 4 show the arrangement. The head employed appears to vary from about 4 to 10 feet, and there is not much object in trying to obtain more. Due to the friction of the sides and the formation of waves and eddies in the very fast-flowing stream of water, it will soon attain a maximum velocity which cannot be increased. Several of the Irish mills mentioned by Fahy¹¹ had troughs with closed ends in which a crude nozzle was bored. Some had wooden covers and some were covered with slabs of stone. This leads to

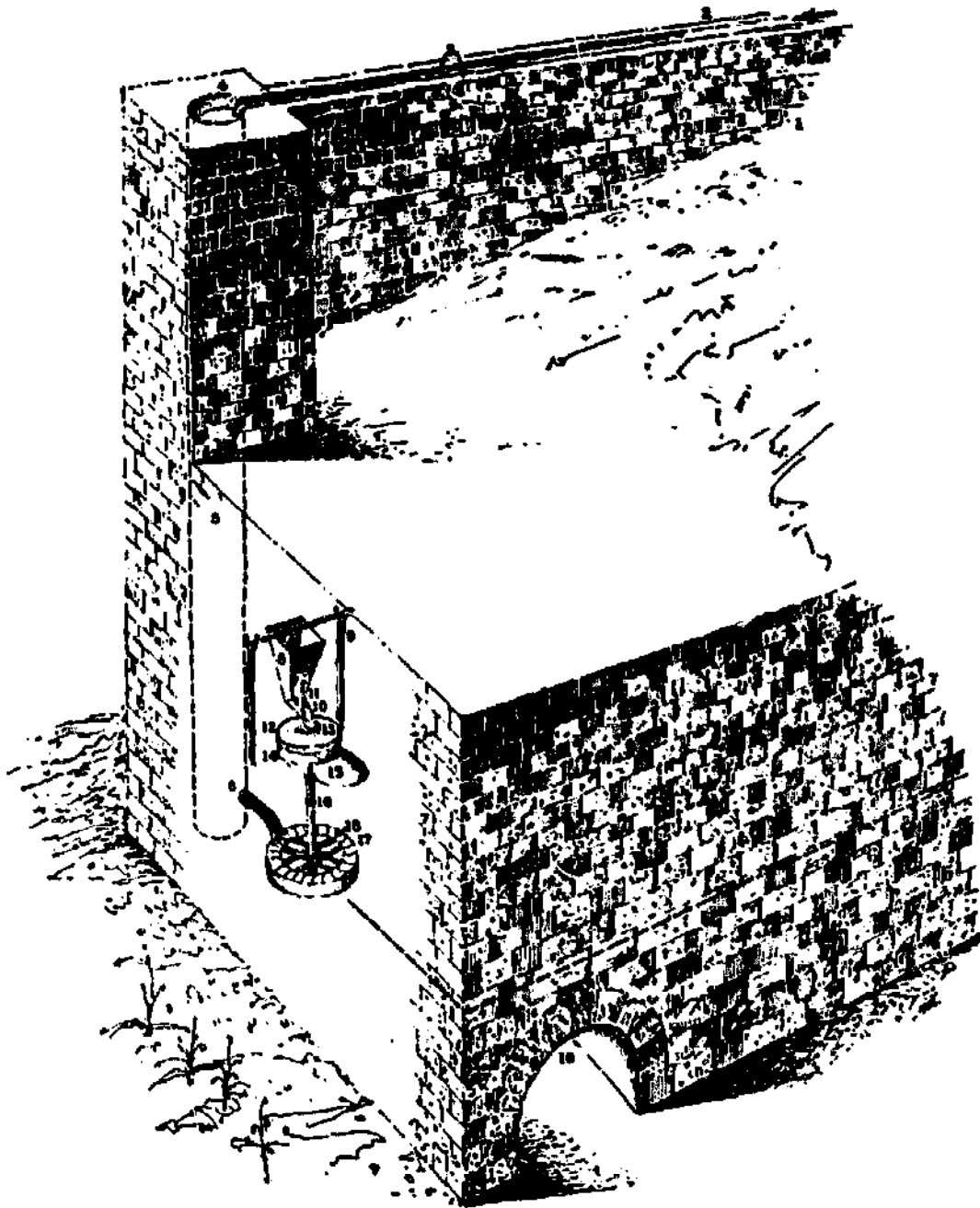


Fig. 3.

Horizontal Mill in Eretz Israel with Aruba Penstock.

From a contemporary drawing by Shemuel Avitsur, Tel Aviv.

the thought that at any rate in some cases, the Irish were using *pipes* instead of *troughs*. The volume of water flowing through the nozzle would be greatly restricted, with the result that the water would back up behind, and the consequent build-up in pressure would give a more powerful and efficient jet. In theory there is no limit to the head which could now be employed efficiently, provided that the relative sizes of pipe, nozzle and wheel are correct. Exactly as with a modern hydro-electric installation, the same amount of power could be obtained by using less water with a greater head.

The same principle applies if a hollow water-tight tower is built adjacent to the mill wheel, and water is admitted from a stream at the top and discharged through a circular nozzle on to the wheel at the bottom. This becomes the "Aruba Penstock" of Israel as shown in Fig. 3 and described in some detail by Avitsur.¹² Referring to Fig. 3, the water is carried round the hillside from the stream and led along the channel "3" to the top of the vertical pipe "5". There was no particular virtue in making the pipe vertical except that it reduced the length and, when working in brick or stone, was reasonably easy to construct. The analogy of building a *well* above ground would almost certainly suggest itself in any country largely dependent upon wells for water supply in many places. The water discharges from the nozzle "6" and turns the wheel. When water is short the nozzle can be replaced by a smaller one. The mill will develop less power, but can still be used, grinding at a lower rate.

Having given a general description of the horizontal watermill I will go on to deal with its history, and give more detail of its occurrence in various countries.

THE HISTORICAL BACKGROUND

John Beckmann, writing his *History of Inventions* towards the end of the 18th century, suggests that watermills were invented in Asia Minor during the 1st century B.C. The evidence is based upon an epigram written by Antipater of Thessalonica rejoicing because the servant girls would no longer have to rise at dawn to grind the corn as the water nymphs would now do the work for them. Beckmann also quotes a reference in Strabo to a "*water-grinder*" which was included amongst the most treasured effects of Mithridates, king of Pontus, listed amongst the spoil after he was defeated by Pompey in 65 B.C.¹³ Bennett and Elton in 1899 and Curwen in 1944 have examined the evidence critically, and are satisfied that Antipater's mill was of the horizontal and not the Vitruvian type.¹⁴ Not all historians agree with this theory. Parsons, after excavating a 5th-century overshot water-wheel in the Athenian Agora is firmly

of the opinion that Antipater was referring to a wheel of this type, and not a horizontal mill.¹⁵ Avitsur supports those scholars who maintain that the writer of the poem was Antipater of Sidon, not Thessalonica, and thinks that very likely the mill to which he refers was in Upper Galilee and not in Greece.¹⁶

Of recent years much more information about the history of technology in China has become available, and our ideas may have to be revised. Bennett and Elton refer to the use of the horizontal mill in China, and Curwen is more positive:

"One would not be at all surprised if it were to turn out that the invention of the vertical watermill originated in the ingenious brains of the Chinese."¹⁷

Dr. Needham states that horizontal water-wheels were being used to operate blowing engines in iron works in China before the Christian era, and Plate 3 shows such a contrivance, the date being c. 1313 A.D.¹⁸

It is interesting to speculate whether the horizontal water-wheel was invented in China, and the design carried in the brain of some enterprising trader along the great east-west trade route, to be developed in Asia Minor for a purpose quite different from that for which it was designed. Needham has shown how the iron and steel industries of China and the West grew up with techniques which were quite dissimilar and this suggests that, even if traders passed from one civilisation to the other, there was little, if any, interchange of technological ideas two thousand years ago. Until more evidence is available, I think that it is only reasonable to assume that there was no connection between the Chinese development of the horizontal water-wheel, to relieve the drudgery of continuously providing a supply of air for a blast furnace, and the ingenious Greek who designed a machine which would enable the servant girls to devote more time to relaxation and less to monotonous work.

THE GEOGRAPHICAL DISTRIBUTION

I now propose to deal with the horizontal mill as it exists to-day or has been recorded in the past. It is difficult to follow any logical path, so I will start with the British Isles and then range further afield, with my information in general becoming more meagre with distance.

SHETLAND

I have already described a typical Shetland mill, and Plate 1 shows the wheel ("Tirl") and three derelict mills on one stream

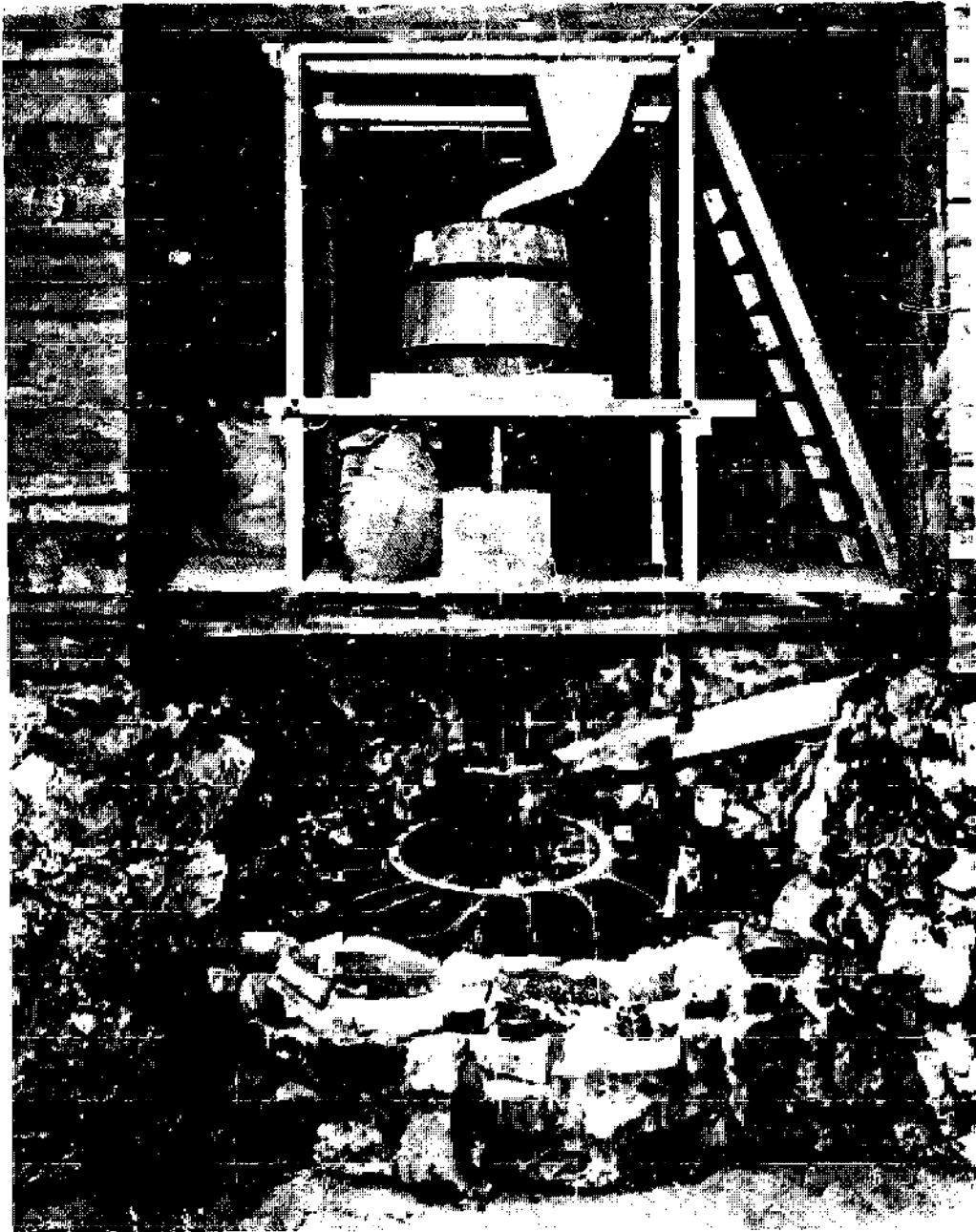
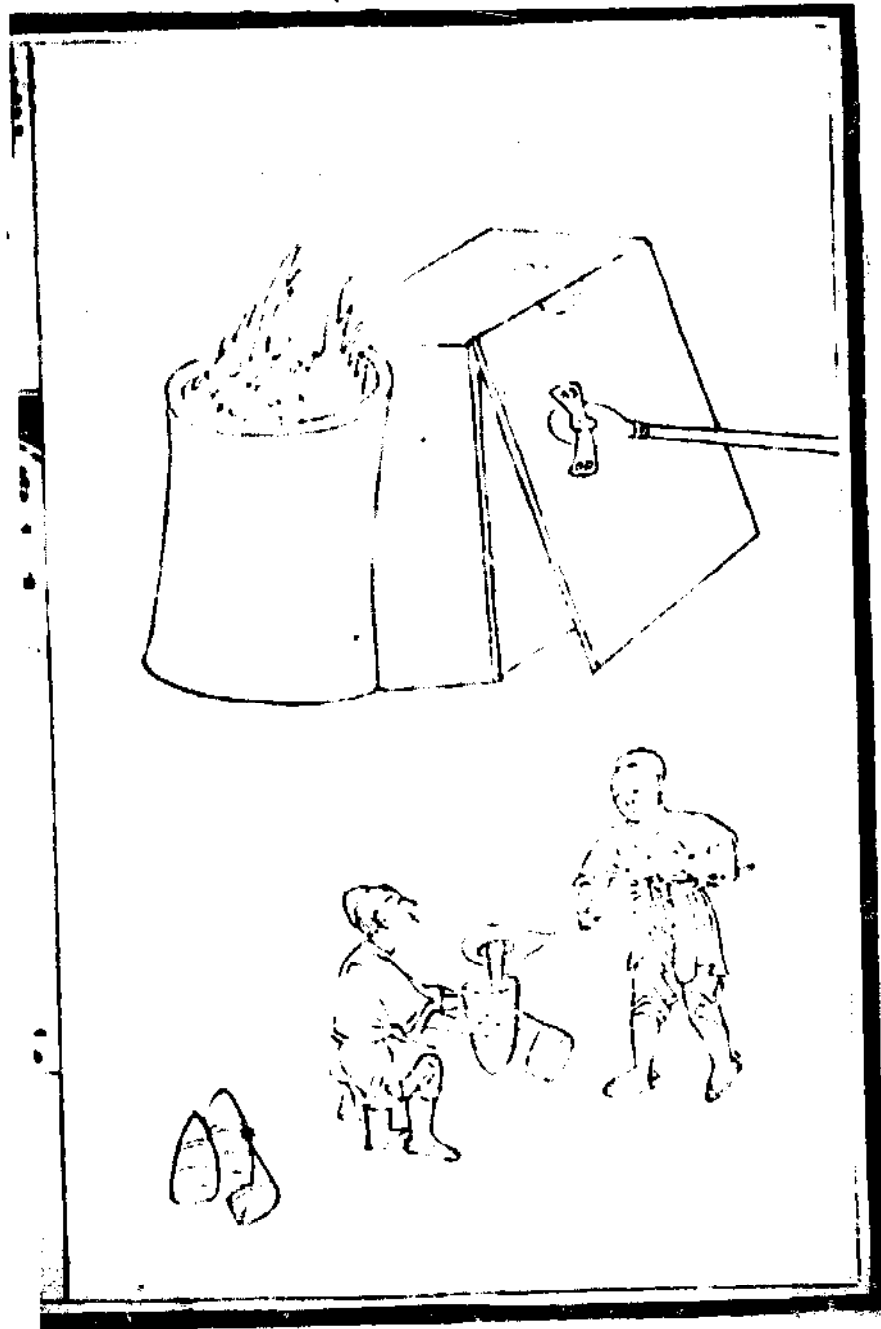


Plate 2.

Alpine Mill.

Re-erected in the Museo Nazionale Della Scienza Tecnica Leonardo da Vinci, Milan.

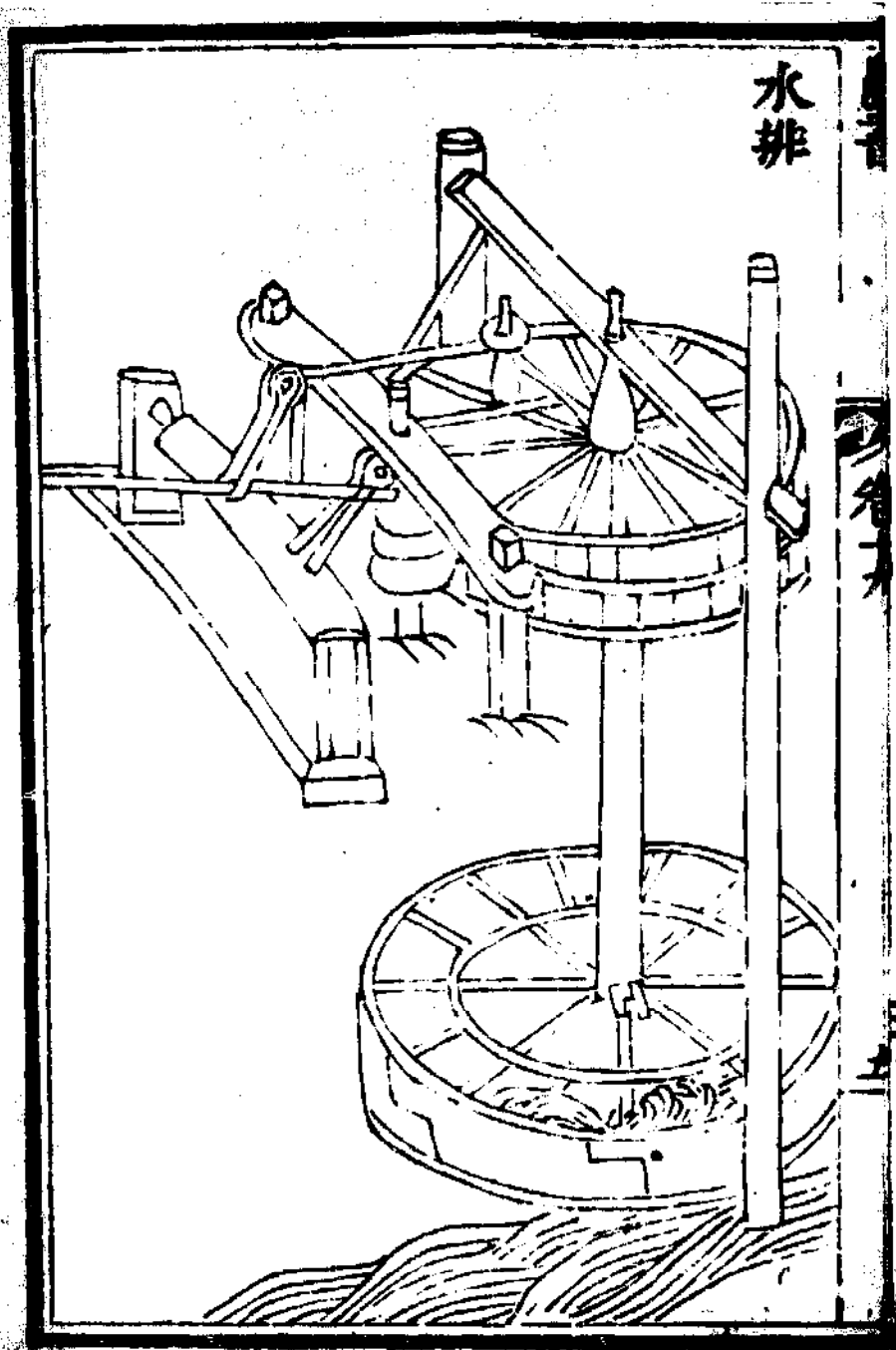
Reproduced by permission of the President, Dott. Ing. Guido Ucelli.



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Chinese Hydraulic Blowing Engine work

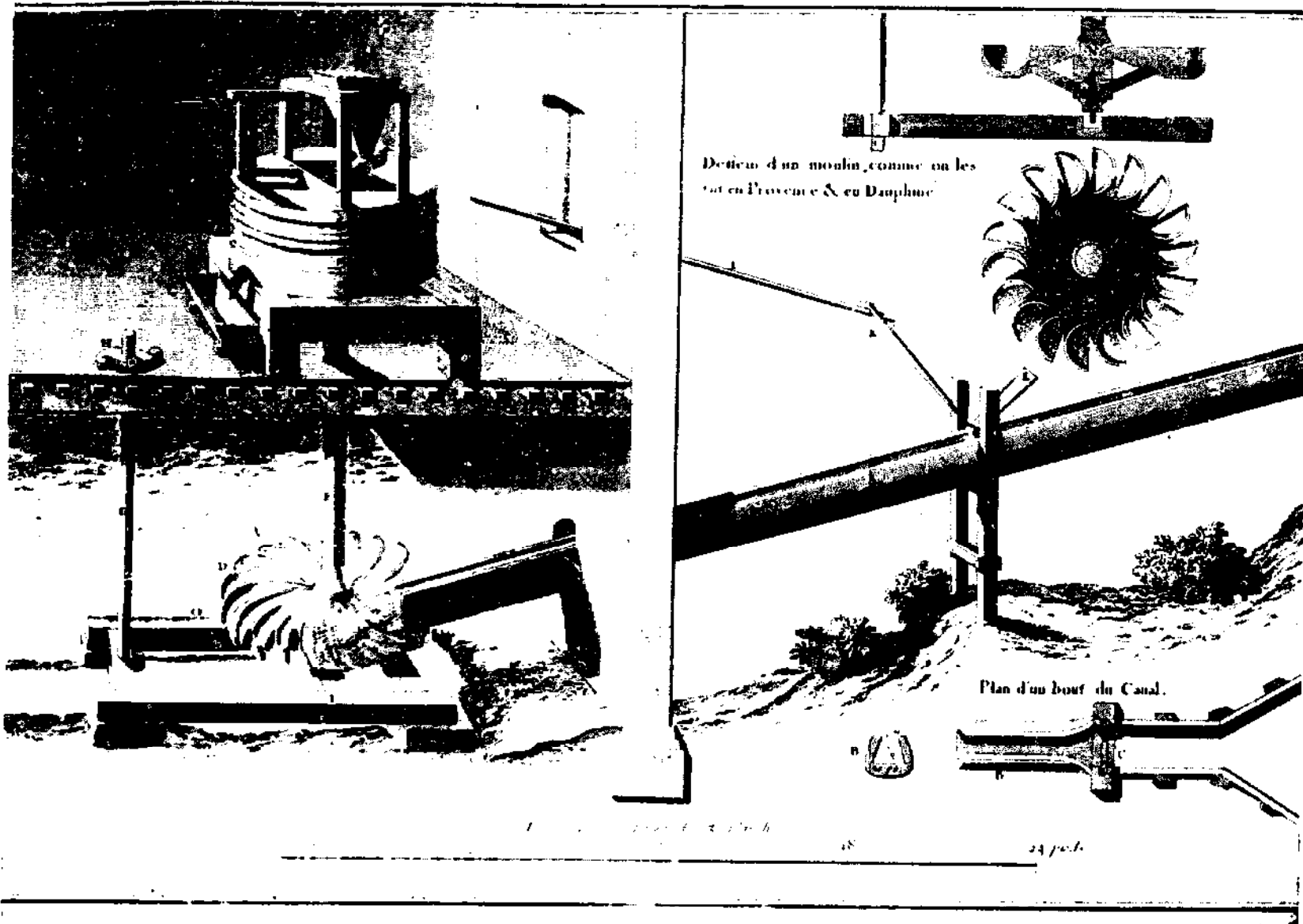
Reproduced from *The Development of Iron and Steel Technology in China*



ate 3.

ed by a Horizontal Waterwheel, c. 1313 a.d.

a' by permission of Dr. Joseph Needham, F.R.S., and the Newcomen Society.



Plâte 4. 18th Century French Horizontal Watermill.
 From 'Architecture Hydraulique', by M. Belidor, Paris, 1782.

placed one above the other so as to make the best use of the available head. The mills were all similar in character, and it is remarkable how many were in use in the late 18th and early 19th centuries. Sir Walter Scott, who visited Shetland in 1814 when he was a Commissioner of Northern Lights, says:

"There are about 500 such mills in Shetland, each capable of grinding more than a sack at a time."¹⁹

The first reference to a Shetland mill quoted by Goudie is from *Low's Tour through the Islands of Orkney and Shetland* published in 1774. Where there was a suitable stream every farm had its own mill, otherwise two or three might share. It was an accepted fact that many of the streams would be dry for several months in the year, and the mills would only be used during wet weather. There was never any attempt to build a mill-pond and store up a small flow to enable the mill to be worked for a few hours only. Now, although some preservation work has been undertaken, there are no mills regularly at work.

CAITHNESS AND THE WESTERN ISLES

Here the picture is much the same as in Shetland, though possibly the mills were less numerous. Dr. Johnson noted in 1773:

"There are water mills in *Sky* and *Ruasa*; but where they are too far distant, the house-wives grind their oats with a quern, or hand-mill . . ."²⁰

It is generally accepted that all these northern mills had flat-bladed "tirls", but Macculloch, writing in 1819 gives the following description of a mill:

"The axis is about four feet long, working on any casual stone by an iron pivot —the only iron in the whole construction. Sixteen or eighteen rude sticks, scooped at their outer ends like a spoon, are driven horizontally into it, their flat sides being vertically placed to catch the stream directed against them."²¹

This wheel must have been constructed very much like the Moycraig wheel of Ulster, as shown in Fig. 2(3). Goudie also refers to a mill at Kirtomy, on the north coast of Sutherland, some 22 miles west of Thurso, which had "feathers" about 2½ feet long.

" . . . concave in form, in order to get the impulse of the water more effectually."²²

This would indicate a wheel at least five feet in diameter which is almost certainly excessive. Those found in Ireland seldom exceeded 3 ft. 6 ins. We have no modern sketch or photograph of this type of wheel from the far north-west, but many of the flat bladed type. Nevertheless it is interesting to note that the more advanced construction has been recorded. The mills appear to have fallen into disuse earlier in Caithness and Sutherland than in Shetland and the Hebrides.

The earliest reference to these mills of the far north which can, with reasonable certainty, be said to apply to *horizontal* mills is one of 1575 quoted by Goudie. This refers to a complaint by the inhabitants of Orkney and Shetland to the effect that Lord Robert Stewart had erected mills of his own, and was compelling the people to use his instead of their own "udal" mills.²³

A mill described as the last of its kind in Orkney was taken over by the Office of Works in 1932. This is the Click Mill at Dounby, which has an unusual wheel with two sets of flat blades, one above the other set in a boss about 2 ft. 6 ins. long. A short but interesting account is given by Stewart Cruden, Inspector of Ancient Monuments for Scotland.²⁴

THE ISLE OF MAN

Although there are only traces of one or two horizontal mills left in the Isle of Man, historical references go back further than they do in the north. In Gibson's translation of Camden's *Britannia*, 1772, Bishop Wilson says:

"Many of the Rivers (or rather Rivulets) not having water sufficient to drive a mill,* the greatest part of the year; necessity has put upon them an invention of a cheap sort of mill. which, as it costs very little, is no great loss though it stands six months in the year. The Water-wheel, about six foot Diameter, lies Horizontal, consisting of a great many hollow ladles, against which the water, brought down in a trough, strikes forcibly, and gives motion to the upper stone, which by a Beam and Iron is join'd to the centre of the water wheel."²⁵

The mills were becoming scarce by the beginning of the 19th century, and have only been mentioned once or twice by more recent writers. Megaw, who has made a critical examination of Manx place-names, produces some interesting evidence relating to the date of their introduction:

"The Norsemen knew the horizontal mill as *kvern* (compare our 'quern'), sometimes prefixed by the descriptive word *skvett*, referring to the squirt of water projected against the paddles of the wheel through a wooden spout or trough. Many places in Norway are still called after these old *Kvernar*, examples of which are used to this day.

That the same type of mill was in use in the Isle of Man in the days of its Norse kings is proved by the name *Corna* = (*Kvern-á*, 'mill-river') by which the *Santanburn* is recorded in the *Chronicon Manniae*, and this is still the name of the river in Kirk Maughold on whose banks are the ruins of the horizontal mill we have described. The valley of this river is named *Kurnadal* (i.e. *Kvern-á dalr*) in a runic inscription dating from the thirteenth century . . .

These Norse place-names prove that horizontal mills were well established in the island at least by the thirteenth century, when the Norse dominion ended."²⁶

* This evidently refers to the relatively large vertical mill with which the Bishop would be more familiar.

IRELAND

Numerous remains of horizontal mills have been found in Ireland and I have already referred to the Moycraig wheel which can still be seen in a state of good preservation in the Belfast Museum and Art Gallery. According to MacAdam, writing in 1856, it was discovered:

"... a number of years ago, in the bog of Moycraig, within one mile of Moss-side, on a farm now occupied by William Hamil, and which is comprised in the district called the Grange of Drumtullogh. The spot is low and flat, and no stream is at present visible near it."²⁷

MacAdam's last sentence sets the pattern for a number of strange facts about the Irish mills, and I cannot avoid a feeling that throughout the ages the leprechauns dwelt amongst them and have done their artful best to make things difficult for modern archaeologists!

Bennett and Elton quote a charming story about the introduction of the mill to Ireland during the reign of king Cormac:

"Among ancient legendary law of the Sister Isle are many traditions of early watermills, the first of them referring to the establishment of a mill at Tara by King Cormac in the third century. Cormac possessed among his various retainers a beautiful bondmaid, Ciarnad, whom the queen condemned to the impossible task of grinding by hand nine quarters of corn a day; this heavy toil being calculated not only to weary out the unfortunate maid, but to keep her safely employed in the bakery the whole day through. Cormac discovering the *ruse*, and immediately taking measures to circumvent her Majesty's intentions, despatched messengers across the sea to, as some say, Scotland, to bring back mechanics who could build a watermill: and in due course the first mill ever erected in Ireland stood 'on the stream' of the Nith; and the baffled queen had no further excuse for compelling the fair Ciarnad to grind by hand."

Unfortunately the accuracy of this story is a matter of considerable doubt as it was not written down until the 11th century, and the authors do not feel that it can be accepted as authentic.²⁸

In recent years much work has been done on the Irish mills by Fahy and Lucas. Dealing with the origin of the mills, Fahy writes:

"The earliest historical references to mills in Ireland occur in three of the annals — Four Masters, Ulster and Tighernach — where we find mention of Maelodran's mill under dates varying between 647 and 651 A.D.

He produces further evidence, all of which suggests that the horizontal mill was in use in Ireland from the 7th century.²⁹

Of the mills excavated, most, if not all, appear to have had spoon-shaped blades. A characteristic feature is the amount of timber-work recovered, much of it well preserved in the bog. Wheels are scarce: they could easily be moved, washed away in a flood or broken up for firewood. Several timber "dams", quite unlike

anything found in Shetland, have been examined. Lucas, describing the dam of the Morett mill, Co. Laoighis, excavated in 1952, states that it was:

"... shaped like a triangle with the apex cut off, the wider and open end to the north. It consisted of a wooden floor bounded by large beams . . . to east and west. It was 476 cm. (15 ft. 7 ins.) long, 188 cm. (6 ft. 2 ins.) wide at the north (upstream) end and 86 cm. (2 ft. 10 ins.) wide at the south end."³⁰

The purpose of this "dam" was to lead water from the relatively broad headrace to the narrow chute. Reference to the sketch at the bottom right hand corner of Plate 4 "Plan d'un bout du Canal", will make this arrangement clear.

I have already referred on p. 5 to the crude nozzles at the end of the chutes, and to the possibility that in some cases the chutes may have been covered and the water discharged through the nozzles under pressure. Here again the leprechauns have been at work. The Mashanaglass "nozzle" was a rough round hole with a diagonal tapered crack at each side which hardly looks natural, but is impossible to explain if it is not. A flume from Kilkenny Castle has two orifices of a distinctly odd shape, one of which was apparently a hole, later broken away to form a slot. It would be reasonable to assume that the larger orifice was normally used and the smaller stopped up by a plug. When water was scarce the plug would be transferred to the larger hole. The flume at Knockrour had a wooden lid and a single round nozzle.³¹ At both Morett and Mashanaglass a considerable amount of timber-work, far more than was used in the Shetland mills, was found in the wheel-house floor. The Morett mill was excavated from a bog which had been drained, possibly by more than one scheme, and Lucas can only hazard a suggestion as to where its water supply originally came from.³²

The Mashanaglass mill, silted up and overgrown, had for many years been regarded as a holy well with remarkable curative properties. The site was excavated by Fahy as a place of known historic interest when it was confirmed that the valley would be flooded in connection with a hydro-electric development, but no one suspected that below the surface of a shallow well would be found the remains of a watermill abandoned more than two hundred years ago.³³

Lucas quotes one further odd fact about the Irish mills:

"It is an extraordinary fact that although mills of this type everywhere attracted the attention of tourists and travellers, Goudie citing no less than seventeen separate notices of the Shetland ones alone, apart from the few general statements already mentioned and some few to be cited later (*in Lucas's paper*) the writer knows of only a single published eyewitness description from Ireland. This is the account given by Knox of two which were still working in

1906, both in the Ballyhaunis neighbourhood, one at the western end of Cullentra Lough in Co. Mayo, the other in the townland of Meeltraum (*Denis Kelly*) which is just across the border in Co. Roscommon. He further adds that such mills abounded in the region . . ."³⁴

The horizontal mill was an ancient and important feature of Irish life, and its construction was more scientifically developed than that of the Shetland mill.

SCANDINAVIA AND THE FAROE ISLANDS

The horizontal mill was used extensively in Norway and Sweden, and some are still working or have been preserved. The construction is virtually identical with that of the Shetland mills. In Denmark there are none left as, according to Jespersen, they had become illegal by 1600.³⁵ Williamson gives a delightful description of a mill working in the Faroe Islands in 1942, but is doubtful if watermills were introduced there before the 18th century.³⁶ The frequent application of the title "Norse" or "Danish" to the horizontal mills found from Eire to Shetland implies that the mill must have come from Scandinavia, but until more information is available this must still be a matter of conjecture.

ENGLAND AND WALES

Before leaving northern Europe I should, perhaps, say a word about the position in England and Wales. We have no proof that the horizontal mill was *not* used in these countries, but unfortunately we also have no proof that it *was*. The artists of the Middle Ages enjoyed drawing windmills and *vertical* (horizontal shaft) watermills which were a prominent feature of the landscape. An example is that shown in the Luttrell Psalter c. 1340.³⁷ Even if horizontal mills existed, they were small and inconspicuous and no one bothered to draw them. It is reasonable to suppose that many of the Saxon mills and possibly a number of those recorded in the Domesday Survey were little horizontal mills, but we cannot be sure. With a manorial system which banned the use of querns (and the smaller horizontal mills were little more than water-driven querns) and strove to establish a manorial mill wherever there was power to drive it and a population to feed it, any "farm" mills must quickly have been displaced. Perhaps one day a lucky archaeologist will discover the unmistakable remains of a horizontal mill in Bedfordshire, Sussex or Kent, and the vexed question will be answered once and for all!

SOUTHERN AND CENTRAL EUROPE

From the Atlantic coast of Portugal to the Black Sea the mill has been used in all districts for many centuries wherever there were swiftly flowing streams. Bennett and Elton, Curwen and other

writers quote descriptions from travel books of the 18th and 19th centuries, illustrated with sketches and photographs of mills in Portugal, Spain, France, Roumania and Turkey. In museums in Munich and Milan, mills, taken from Alpine streams, have been re-erected and are arranged to run round, with water pouring down their chutes. The mill in the Leonardo da Vinci Museum in Milan is shown in Plate 2. What may well be the earliest drawing of a mill with a horizontal wheel is contained in a German manuscript in the Munich Library dated about 1430. An artist's impression (by Mr. K. C. Reid) is given on the front cover of this booklet. It shows a wheel of unusual design with four spokes and a vertical shaft. Above is a millstone and the familiar hopper and spout. In the background a castle stands on a hill down which a stream rushes to turn the mill. There is no suggestion of a chute.³⁸

The horizontal mill assumed much greater importance in southern and central Europe (and in Asia Minor) than it did in the more northerly countries. Many of the wheels were larger and of more efficient design; they were contained in well built permanent structures, and sometimes two wheels and two pairs of stones were installed in one house. Water was supplied down an open chute or under pressure through a wooden nozzle. They would not be as efficient as an overshot or breast wheel, but they had the virtue of simplicity due to the absence of gearing. The mills shown in Plates 4 and 5 can hardly be compared with the simple Shetland "farm" mill.

Plate 4, taken from Belidor's "Architecture Hydraulique", 1782, is an engineer's design of a mill as used in Provence and Dauphiné. It is fed by an open chute with a tapered trough at the upper end similar to those found in Ireland.³⁹

I am most grateful to doña Matilde López Serrano, Director of the Library of the Royal Palace, Madrid, for permission to publish the illustration in Plate 5. This is copied from the original architect's drawing of the *compania* mill at the Monastery of the Escorial outside Madrid, built by King Philip II. It was started in 1563 and completed in 1584. The drawing is undated, and was made by Fransisco de Mora, who was assistant to Juan de Herrera, the architect. There are a few notes on the drawing, but nothing to suggest that it was not a straightforward mill of a type with which the builders would be familiar. It will be noted that the water is admitted under pressure through a nozzle, (as with the Aruba Penstock) and the plan view, not reproduced, shows that two wheels and two pairs of stones were installed. The mill formed part of the domestic offices of the Monastery, including laundry, etc., and has only recently been demolished.⁴⁰

In the late 18th and early 19th centuries the French engineers devoted more and more research to the horizontal water-wheel. Le Comte de Lasterie, writing in 1823, gives a description and

illustration of a rice mill with a horizontal wheel having eight straight blades and apparently discharging the water through an annular space at the centre. He states that these wheels were in use in Valence and that similar wheels are found in Spain.⁴¹ Belidor describes an installation at Toulouse with an illustration showing three horizontal water-wheels placed close together. The wheels are quite like those of a modern turbine designed to operate with a low head of water. They ran in enclosed chambers, and the water was admitted at one side through an opening which was under pressure. There are points of similarity with the American "Tub-wheel" described on p. 16.⁴² In 1822 Piobert and Tardy carried out efficiency tests upon some vertical shaft water-wheels,⁴³ and five years later Benoit Fourneyron opened the gates to a new era with the invention of his vertical shaft outward-flow water turbine.⁴⁴

ISRAEL, CYPRUS AND CRETE

Avitsur, whose description of the Aruba Penstock has been referred to on p. 7, has made a comprehensive study of the development of the horizontal mill in Eretz Israel and has carried his researches further afield. In the English summary of his thesis he states:

"Springs whose flow increases in winter . . . were put to use during the winter and early spring months. Thus in spite, or more precisely because, of the insufficient water supply in the land of Israel, ways and means were found of exploiting the available water under conditions and on a scale previously unknown and unrequired in any other part of the world except perhaps our northern neighbours.

The first mention of a water mill is found in a Talmudic source known as Tosefta, where use on the Sabbath day is prohibited. The same passage is also quoted in the Jerusalem Talmud, which explains that the prohibition was decided on following certain controversies between the schools of Hillel and Shamai. As these schools were in existence before the destruction of the Second Temple in 70 A.D., it means that the operation of water mills according to Jewish law was under discussion no later than the early part of the First Century . . ."

He considers that the early mills were built in the stream beds, then the fall was increased by introducing the sloping chute with which we have become familiar, and finally the Aruba Penstock was introduced giving much greater efficiency and enabling useful power to be obtained from quite small flows of water using heads up to 25 or even 30 feet.

The mills were used for fulling and the production of olive oil as well as for grinding corn. In 1900 there were about 200 water-mills at work in western Palestine, the numbers falling to 135 in 1922, 55 in 1928 and 4 in 1950. The last mill ceased to operate

in 1955, but Avitsur is making strenuous efforts to have at least one preserved.

The wheels are larger in diameter than most of those we have considered. This is to be expected when a high head of water and small quantity are to be used to the best advantage. Some of the wheels had long wooden blades not unlike the "Balkan" type, Fig. 2(5), but most were as indicated in Fig. 2(6). The blades and inner and outer shrouds were of iron, most being beat to an angle of about 90° in a horizontal plane. Occasionally they were curved like the half section of a pipe.⁴⁵

I believe that in Crete the development and use of the mill proceeded upon parallel lines,⁴⁶ and I am told by Avitsur that there are still some horizontal mills working in Cyprus but that the form of the penstock and wheel differ from those of Israel.

ASIA

I have mentioned briefly the horizontal mill on the Mediterranean coast of Asia, but of its use throughout the vast continent from the Black Sea to the Pacific coast I can say but little. Needham states that it was first used for furnace blowing, and later for corn grinding. Bennett and Elton and Curwen quote several travellers references to seeing the mill in China, and I have little doubt that tens, if not hundreds of thousands of these mills may still be found until the march of progress sweeps them away.

THE UNITED STATES OF AMERICA

With a tremendous influx of population from Europe to America during the 18th and 19th century it would indeed be surprising if the horizontal mill had not been used by settlers who were always short of manpower.

Oliver Evans devotes some pages of his book "The Young Millwright and Miller's Guide", 1826, to the design and construction of "tub wheels". He first describes a vertical shaft mill, the construction being generally similar to that of the Shetland mill, but with three main points of difference. The wheel is surrounded by a stationary shroud or "tub". The water discharges on to it from a closed penstock giving an effect somewhat similar to that of the Aruba Penstock, but the flow is controlled by a sluice and the jet of water is rectangular in cross section. The third point of difference is the suggestion that in order to obtain more power two streams of water should be admitted at 180° to one another. Evans gives a small scale sketch, but does not amplify the latter proposal by showing in any detail how the two penstocks, one at each side of the wheel, should be constructed.

He states that with a head of 8 feet the rill will drive a 5 ft. stone and although admitting the disadvantages of this type of wheel, due to low efficiency and power, he strongly advocates its

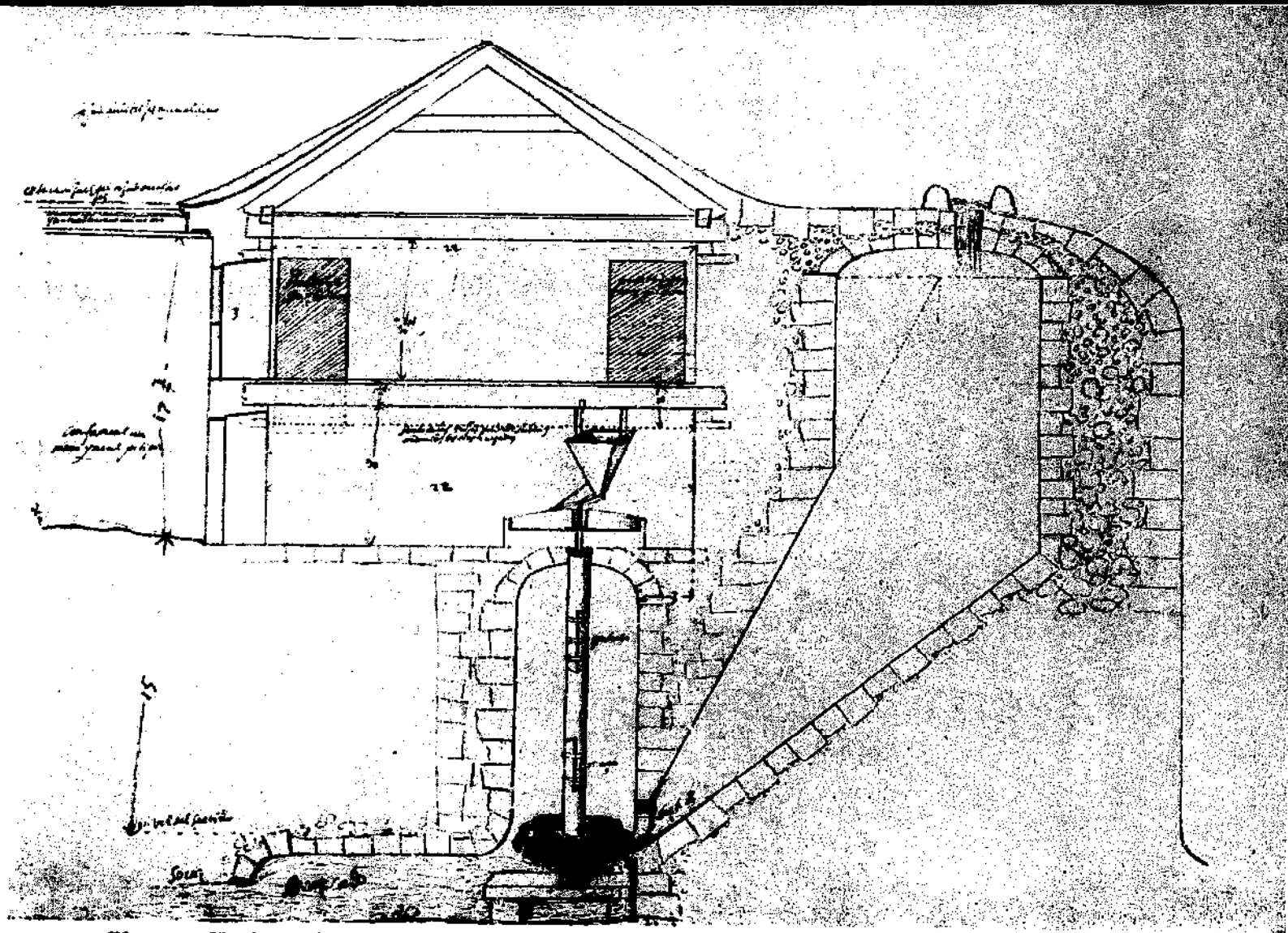


Plate 5. Horizontal Mill for the Domestic Buildings of the Monastery of El Escorial, Spain, c. 1580.

Reproduced from 'Trazas de Juan de Herrera para el Monasterio de El Escorial' Plate XXXVII, Patrimonio Nacional, Biblioteca del Palacio, Madrid, 1944, by the kind permission of doña Matilde López Serrano, Director of the Library.



Plate 6.

Horizontal Mill, Gamkas Kloof, Nr. Calitzdorp, C.P., South Africa.

Front view of Mill showing Hopper feed mechanism. Adjusting screw (for clearance between grind stones) shown on right attached to chain.

Photograph by Brian Harris, Capetown, 1959.

use in all cases when a head of at least 8 feet can be obtained and there is ample water. He points out the advantage of simplicity and low cost. Some tables of performance, calculated theoretically, are also included in this excellent and most informative book.⁴⁷

Uehling, writing in 1954, gives a brief description and drawing of a tub wheel, indicating a form of construction and operation generally similar to that of Evans. He states that isolated wheels of this type were found in old mills at the end of the 19th century.⁴⁸

There is also reference to a tub wheel in an article in the *National Geographic Magazine* of August 1936, together with a photograph which shows a very ramshackle timber building in Tennessee, with a wooden chute leading down to the wheel. The wheel itself is not shown and the author states that the mill is called a tub wheel because it will only grind one tub of meal at a time. This is probably incorrect as there can be little doubt that the name is in fact taken from the "tub" which normally surrounded the wheel.⁴⁹

SOUTH AFRICA

Finally we pass from the northern to the southern hemisphere where I, at any rate, had never expected to learn that horizontal watermills almost indistinguishable from those of Shetland were still, in 1959, busily at work.

The first reference comes from Thomas Pringle, writing about 1820. He describes a farm called Elands-Drift, in the valley of the River Tarka, about 130 miles from Port Elizabeth:

"... which was the residence of an old Dutch-African Boor (*sic*) named Winzel Coetzer.

After the folding of the cattle was over, my host showed us his corn mill, which was of very small dimensions and simple construction. The water-wheel, which was driven horizontally by the little canal of irrigation on its passage to the orchard was only about five feet in diameter, and the millstones not more than two. A slender iron axle of which the lower end was fixed in the horizontal water-wheel, passing through a small hole in the centre of the nether millstone, was mortised into the upper one, which by this means was put in motion. The corn was supplied by an orifice in the upper stone, and the flour conveyed by a little wooden spout into a leathern bag; and this was the whole machinery. I was informed that it would grind about a bushel of wheat in eight hours."⁵⁰

In 1958 Mr. Alan Telford of Johannesburg informed Miss Gardner that he understood that some mills were still working in Gamkas Kloof, Cape Province, sometimes known as "die Hel". This is an isolated valley, difficult of access, in the Zwartburg mountains roughly half way between Elands-Drift and Capetown. The town of Prince Albert lies to the north, and Oudtshoorn — famous for its caves — to the south. Within the valley there is an Afrikaner farming community whose way of life has been largely untroubled

by the developments of modern civilisation. In July 1959 Mr. Brian Harris, an engineer (and fortunately also a mountaineer) from Capetown trekked into Gamkas Kloof and has sent the following description of the Mills:

"After inspecting one or two of the wheels it was clear that there was no standard design nor any real effort at technical perfection. On the contrary, there is a large degree of improvisation, although basic principles are maintained. The grinding stones themselves are the only items in the mechanism which are imported. They are specially made to order in Calitzdorp. (One of the nearest towns.) Some are provided with radial grooves, and there seems to be no standardisation on this point. All the other bits and pieces are put together with material available in the Kloof."

He goes on to say that there are five mills, three of which he saw, although one was temporarily out of commission. There was some difference in wheel construction, some being unshrouded as Fig. 2(1), and some shrouded as Fig. 2(2). He photographed the wheel of Mr. W. C. Mostert, aged 72, who was born on the farm where he then lived and whose 92 year old father had just died. The latter came to the farm as a boy and the mill was there then. There can be little doubt that the horizontal mill has been a feature of Gamkas Kloof for over 100 years and perhaps much longer.

The description given by Harris (who had never seen or read about a Shetland mill) could almost be that of Dickinson and Straker. The wheel has an iron spindle and there is a wooden bush in the lower stone. The upper stone hangs freely on a "rbind" (Harris's description: "Rectangular locking plate recessed into upper grind stone. This is loose in slot") and the spout of the hopper is shaken by means of a wire rod projecting into the eye of the upper stone. A cam is arranged to strike the rod and vibrates the spout sufficiently to feed one or two grains into the stones at each revolution. The bottom bearing is fixed to an adjustable beam (the "sole tree") which can be raised or lowered to give the correct gap between the stones. Plate 6 is a photograph by Harris; this shows the almost primitive construction of the mill, and will help to explain the very condescending descriptions given by some early writers who could hardly bring themselves to compare this simple contrivance with the big flour mills which were prominent features of the countryside.⁵¹ It will be noted that this mill has no "upper house", though in a very rough sketch of "A Mill in Gamkas Kloof" (undated) sent to Mr. Telford by Mr. A. C. McCrindle a thatched roof is shown.

According to Mr. Immelman, librarian to the University of Capetown, watermills were established in the western part of the Cape of Good Hope as early as the 17th century, but the usual difficulty arises in determining whether these were horizontal or vertical mills, and further research may enable the date of the

introduction of the horizontal mill and the European source from which it originated to be accurately agreed. The use of the "farm" (horizontal) mill in Cape Province within the last fifty years was, apparently, more widespread than I had suspected.⁵² Immelman attributes the continued use of the mill in Gamkas Kloof only to the isolation of the valley, but Harris states:

"I do not think that there is any danger of these mills lapsing into disuse once the new road is made into Gamkas Kloof and access to centralised bulk milling installations in Prince Albert is made easier. They claim that the flour produced on these mills is superior to any that is bulk produced, since there is apparently a tendency with the latter to overheat the finished product."

It is surprising and cheering to find that, in a country as modern and progressive as South Africa, the horizontal mill is still being used, maintained and appreciated, and we can only hope that the mills of Gamkas Kloof will long continue to turn.

THE ADVENT OF THE WATER TURBINE

The progress of civilisation can be gauged almost entirely by man's success in harnessing the forces of nature to do his work for him. Antipater's cheerful little epigram proclaimed the introduction of a new era, and though the rate of advance was at first slow, more and more use was steadily made of water power. In populous areas and for industrial purposes the vertical waterwheel, developing greater power at a higher efficiency, soon drove out the little horizontal mills. Then came Fourneyron's outward flow reaction turbine, soon to be followed by the designs of Francis, Thomson, Jonval, Girard, Kaplan and countless others. Nearly all the early turbines had horizontal wheels with vertical shafts, like the horizontal watermills, but the drive to the machinery was transmitted through bevel gears and belts.

The vertical shaft Pelton Wheel is a comparative newcomer to the water turbine world and is an interesting reversion to the basic principle of the earliest of the horizontal mills. The Pelton Wheel itself, a steel casting with its huge "buckets" ground to a mirror finish with great accuracy of profile, is secured to the bottom end of the shaft. Water under a high pressure flows through the nozzle and strikes the buckets as it did in the mill at the Escorial. In place of the upper grindstone the rotating part of an electric generator is secured to the upper end of the shaft. It is interesting to reflect that whereas the wheel of Antipater did the work of one or two girls, each vertical shaft Pelton Wheel at Kemano in British Columbia has a wheel 13 ft. 6 ins. in diameter and does the work of 140,000 horses. The head is 2,500 feet and this one power station, working 24 hours per day, produces more energy than many millions of men. The watermill with a horizontal wheel has come back into its own!

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- ¹⁰ Shemuel Avitsur, *On the History of the Exploitation of Waterpower in Eretz Israel*. Avehsalom Institute for Homeland Studies, Tel-Aviv, 1960. (In course of publication.)
- ¹¹ Fahy, Op. Cit., Fig. 7.
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- ¹³ John Beckmann, *History of Inventions*, London, 1846, pp. 151-2. The first English edition was printed in 1797.
- ¹⁴ B. & E., Op. Cit., pp. 6-8. Curwen, Op. Cit., pp. 134-5.
- ¹⁵ A. W. Parsons, *A Roman Water-mill in the Athenian Agora*, Hesperia, Vol. V, 1936, pp. 70-90.
- ¹⁶ Avitsur, Op. Cit.
- ¹⁷ Curwen (Op. Cit., p. 145) refers to *vertical* mills as mills with *vertical* shafts. As an engineer I prefer this definition, and used it in No. 1 of the S.P.A.B. series, *Watermills — an Introduction*. In view, however, of the fact that the adjectives *horizontal* and *vertical* are almost universally applied by those interested in water-mills to *the plane in which the wheel lies*, the wording of this booklet has been altered to accord with what is undoubtedly the majority view.
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- ²⁰ Samuel Johnson, *Journey to the Western Islands of Scotland*, Oxford Univ., 1924, p. 93.

- ²¹ John Macculloch, *A Description of the Western Islands of Scotland*, London, 1819, Vol. II, p. 30. The description quoted by Goudie is contained in a footnote which gives no indication as to where Macculloch had seen a mill of this type. He draws attention to the fact that in St. Kilda there are several streams which could have driven such a mill, but that only hand querns were used.
- ²² Goudie, *Op. Cit.*, p. 283, quoting a Mr. Mackay, who had seen this mill working ". . . in his early days", presumably c. 1830.
- ²³ *Ibid.*, p. 282. Apparently the term "udal" may be roughly translated as "freehold", though I am informed that this is not strictly equivalent.
- ²⁴ Stewart Cruden, *Click Mill, Dounby, Orkney*, H.M.S.O., Edinburgh, 1949, 4 pp. with sketches.
- ²⁵ Gibson's *Camden's Britannia*, 2nd edn., Vol. II, 1722, p. 1448. The information relating to the Isle of Man was communicated by Bishop Thomas Wilson, p. 1442.
- ²⁶ B. R. S. Megaw, *Mwyllin Beg: An account of the Horizontal Mills*, Journ. Manx Museum, Vol. IV, No. 63, Dec. 1940, pp. 199-202. Megaw comments upon the relatively large wheel diameter mentioned, and suggests that the printer's eye may have wandered to the line above. It seems unlikely that many of these early investigators climbed through the narrow tail-race entrance with a rule or tape to measure the diameter of the wheel, and looking into a dark, dripping chamber, their estimates may well have been inaccurate. On the other hand the wheel shown in Belidor's illustration (Plate 4, date 1782), is about 8 feet in diameter.
- ²⁷ MacAdam, *Op. Cit.*, p. 6. The site is a few miles south of Ballycastle, Co. Antrim.
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- ³¹ Fahy, *Op. Cit.*, p. 26.
- ³² Lucas, *Op. Cit.*, p. 26.
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- ³⁴ Lucas, *Op. Cit.*, p. 8, quoting H. T. Knox, *Proc. Soc. Royal Irish Academy*, 26 C., 1906-7, pp. 265-273.
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- ³⁷ See C. P. Skilton, *British Windmills and Watermills*, London, 1947, p. 39, for a reproduction of this picture.
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- ³⁹ M. Belidor, *Architecture Hydraulique*, Paris, 1782, Book II, Ch. I. Plate 4.
- ⁴⁰ Matilde López Serrano, *Trazas de Juan de Herrera y sus Seguidores para el Monasterio del Escorial*, Patrimonio Nacional, Biblioteca del Palacio, Madrid, 1944, Lamina XXXVII & XXXVIII.

- ⁴¹ Le Comte de Lasteyrie, *Collections de Machines Etc.*, Paris, 1823, Tome 1, Pl. 9, p. 76.
- ⁴² Belidor, *Op. Cit.*, Book II, Plate 5. Bennett and Elton and other authors have reproduced parts of this plate.
- ⁴³ Piobert and Tardy, *Experiences sur les Rues Hydrauliques a axe Vertical*, Paris, 1840.
- ⁴⁴ It can hardly be said that Fourneyron's turbine was a direct development of the horizontal mill, but it had more in common with this type of wheel than with the large *vertical* waterwheels which, at that time, provided the main sources of power for the Industrial Revolution.
- ⁴⁵ Avitsur, *Op. Cit.*, and correspondence 1959.
- ⁴⁶ Information and sketch from Dr. F. H. Stubbings, Emmanuel College, Cambridge, who visited Crete in 1940.
- ⁴⁷ Oliver Evans, *The Young Millwright and Miller's Guide*, Philadelphia, 1826. pp. 157-162.
- ⁴⁸ Edward Uehling, *Water over the Dam*, Allis Chalmers Mfg. Co., Milwaukee, Wis., 1954, p. 9.
- ⁴⁹ *National Geographic Magazine*, Washington, D.C., Vol. 70, July—Dec. 1936, p. 262.
- ⁵⁰ Thomas Pringle, *African Sketches*, London, 1834, p. 182. This is described as a 'later edition' of Pringle's work, and his visit to Elands Drift probably took place ten to fifteen years earlier.
- ⁵¹ Possibly the most extreme example of this scornful attitude is to be found in *The Pirate*, by Sir Walter Scott, when Mr. Yellowley, a Yorkshireman exiled to Shetland, pours derision on the simple Shetland mill.
- ⁵² Correspondence with Mr. R. F. M. Immelman, Librarian, University of Capetown, 1959.

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