Barbegal watermills

Rome's revolutionary power

When they were built in the 2nd century AD, the great watermills at Barbegal, in the South of France, were at the very cutting edge of technology. Their revolutionary design, says **Wayne Lorenz**, enabled the Roman Empire to flourish, and endured unchanged until the 20th century.

MAIN IMAGE The lower east portion of the Barbegal watermills today. The higher walls are the millstone rooms, with the waterwheel boxes to the right.

It is hard to imagine what the local people thought when they saw the great watermills at Barbegal crank into action for the first time. Certainly it must have been an impressive sight: 16 huge waterwheels stretching downhill in pairs, the water being scooped up by each set and dropped down onto the pair in front, cascading from one pair to the next down until it finally reached the bottom of the slope where it drained away. Attached to each of the mighty wheels was the grinding mechanism that milled the grain into flour. This huge complex, built in the 2nd century AD just outside *Arelate* (modern-day Arles) in the South of France, marked a turning point in food production, enabling bread to be made on an industrial scale. Significantly, it represented a revolutionary advancement in design from small, animal-driven mills to powerful water-powered machines, a leap in engineering that held its own for nearly 2,000 years.

The milling of grain has been practised for millennia: traces of starch grains on

Upper Palaeolithic hand tools suggest the practice of hand-grinding cereals dates to at least 23,000 years ago, and, indeed, some evidence suggests wild grass seeds were being ground into flour as early as 45,000 years ago. As society evolved, so more-efficient methods for grinding cereals were developed to increase the productivity necessary to feed a growing population.

ABOVE This example of an animal-driven mill, found at Pompeii, would have been powered by a donkey or mule.

Horse to water

The Romans relied primarily on animal-driven mills, such as those that can be seen today attached to the bakeries uncovered at Pompeii and Ostia. They were powered by brute force and gravity. Donkeys and horses provided the power, turning the millstones at low rotational speeds. Stones with a steep grinding plane allowed gravity to carry the grain from the inside of the stone, where it was fed in, to the stone's outside edge, where the flour emerged. These hourglass-shaped stones (see photo above) were common throughout the Roman Empire and ranged in diameter from 45cm to 64cm (18in to 25in).

Although this method was slow, it was efficient, and remained in use for a considerable time. The introduction of water power to replace animal power, however, ramped up the level of production.

The use of water power for milling by the Romans was recorded by Vitruvius in the 1st century BC, and a number of archaeological sites demonstrate the Roman use of water to power millstones. Just as with the Roman arch in bridge and building structures, Roman engineers did not actually invent the water-driven mill; but – again, just as they did with the arch – they exploited this hydropower technology much more widely than their predecessors, designing the new mills to take advantage of water that was already being transported via great aqueducts to their urban centres like *Arelate*.

Key to this new process was the use of a waterwheel and gearing to turn the millstone, the heart of the milling process. The millstone gradually evolved from the steep-sided animal-powered versions to become greater in diameter and squatter in shape, and, therefore, with a much-reduced grinding plane. Crucially, the millstones were driven by gears that greatly increased the rotational speed. Thus, the resulting centrifugal force, rather than gravity, was sufficient for the grain to pass from the inside of the millstone to the outside edge of the stone, which meant that much flatter stones could be used.

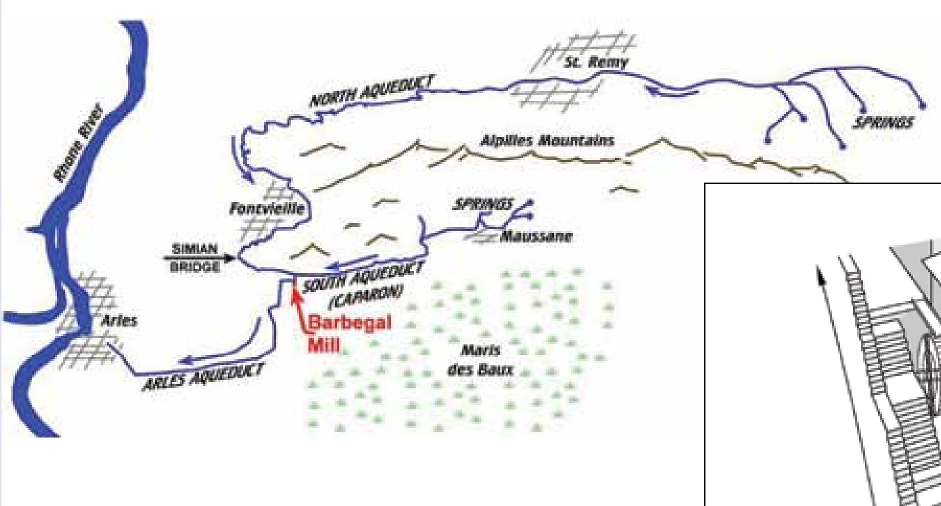
BARBEGAL: ARCHAEOLOGY IN BRIEF

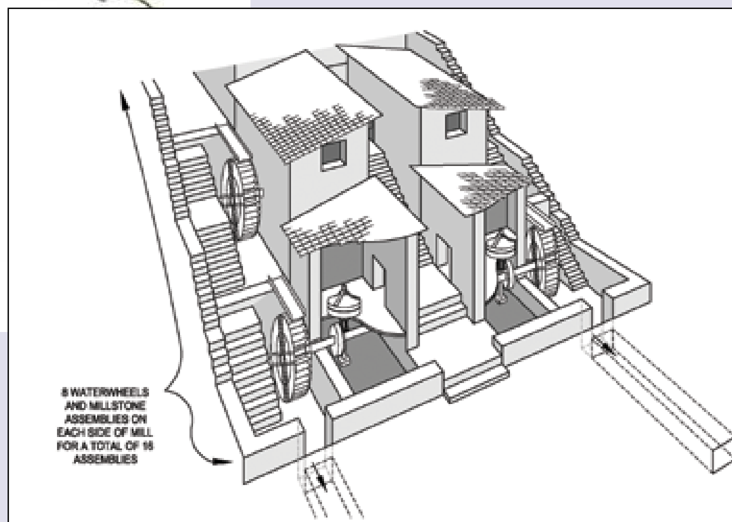
The Barbegal watermills were first investigated in 1937-1939 by François Benoit, who published his results in 1940. Based on pottery finds, Benoit believed the mill was constructed at the tail end of the 3rd century AD, in response to the emperor Constantine's move to nearby Arles, which he made his capital in AD 408. The site, Benoit suggested, was built in response to the increased requirements of the emperor's soldiers and the population as a whole throughout the region.

However, Benoit's interpretation was mistaken: the pottery was actually associated with later occupation and destruction layers. Investigations in the 1990s have now determined that the mills were actually constructed at least two centuries earlier. Excavations directed by Kevin Walsh of York University, as part of a wider programme of research in the area led by Philippe Leveau, uncovered a *denarius*, dated AD 103-111, embedded in the mortar of part of a mill's hydraulic installations. The small silver coin, depicting the emperor Trajan who died in AD 117, was in good condition, suggesting it had not been in circulation for any length of time, and, crucially, it provided a *terminus post quem*.

Furthermore, a number of sherds and more coins were uncovered in a drainage ditch just outside the channel that carried water from the mills at its base: these reveal that Barbegal enjoyed its peak of activity between the 2nd and early 4th centuries.

According to Leveau, construction of the watermills coincided with a spike in major building activity in Arles, and Barbegal would have supplied flour just to the city – rather than to the whole region, as Benoit had proposed. While it appears the site fell out of use in the 4th century, exactly when and why it was finally abandoned remains unclear, although it could simply have been replaced by a new mill on the Rhône.





ABOVE A schematic plan of the Barbegal aqueduct system providing water to the Barbegal watermills and the Roman city of *Arelate* (Arles).

RIGHT Drawing to show one of the eight sets of watermills, illustrating the waterwheel and grinding mechanism.

Barbegal watermills

Barbegal is a unique site in that it represents a transitional period in design from the early animal-driven mills to the water-powered machines, clearly demonstrated by the shape of the millstones, which are hybrid versions of the hourglass and flat designs.

The mills are located in the Roman province of *Gallia Narbonensis*, and operated from the 2nd through at least the 4th centuries AD. They were fed by the great aqueduct system built to bring drinking water from the local mountain range, Les Alpilles, to *Arelate*, but which was then later modified to provide water to both the city and Barbegal. Its site near *Via Aurelia*, a major highway in southern Gaul, was probably located on an inland marsh or waterway that connected with the Mediterranean Sea. The surrounding area was a prime agricultural region; indeed wheat and other grains are still grown here today – and feature in some of the great works of art by 19th-century Post-Impressionist Vincent van Gogh.

There were numerous installations of waterwheel-driven mills in the Roman Empire, but Barbegal was unique in that it had 16 water-powered millstones. As such, it is probably the largest known milling installation of its kind in the Roman era.

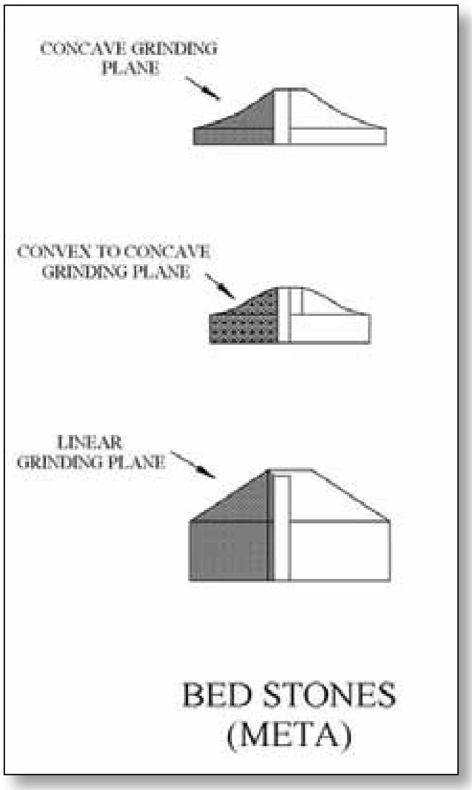
Barbegal millstones

The best-preserved Barbegal millstone is a bed stone that has a diameter of 76cm (2ft 6in) and a depth of 44cm (1ft 5in) at the axle (see photo below left). The diameter of this bed stone falls within the range of most rotary-powered millstones that have been discovered from Roman antiquity, which range from 55cm (1ft 10in) to 85cm (2ft 9in).

Other millstone fragments discovered in the area of the Barbegal site, and also now at the Musée de l'Arles, have specific design differences between them (see photo below). Notches in the top of the runner stone were filled with lead to

ABOVE Side view of a Barbegal bed stone from the Musée de l'Arles et de la Provence Antique in Arles.

MIDDLE & RIGHT Plan and side view of a runner millstone segment. Note the holes that were used to hold the assembly that rotated the runner stone. One of the holes has been filled with lead to firmly anchor the assembly.



ABOVE Drawing showing the convex and concave grinding planes of bed-stone fragments found in the Barbegal area.

anchor metal fittings to an axle that was used to turn the runner stone.

Several of the millstone fragments have diameters that range from 66cm (2ft 2in) to 76cm (2ft 6in). Two other examples have much smaller diameters (48cm/1ft 7in and 54cm/1ft 9in) and have a different design, including the shape of their grinding-plane surfaces (see box and illustration right).

These millstone differences could have been intended by the Roman engineers to test varying designs in an effort to develop the most efficient millstone for water-powered mills. The technology regarding rotational speed and millstone shape that was engineered and refined at Barbegal may well have had a significant impact on advancing the knowledge of the mass production of flour: more could be produced with greater control of the product. Although there is no written record, knowledge obtained here was passed down from master to apprentice until the Industrial Revolution.

The millstones that have survived are of the basaltic rock type (see photograph on following page), which were chosen by Roman millers because of the small cavities, or vesicle texture, that provide the cutting and grinding edges needed for processing the grain. There are some questions as to their origin, but we do know that the stones do not come from the same quarry locations. Since the city of *Arelate* was located nearby, and it was an important port city in Roman times, the Barbegal millstones could have been brought in as ship ballast from various Mediterranean locations. ▹

MILLSTONE FUNCTION AND EVOLUTION

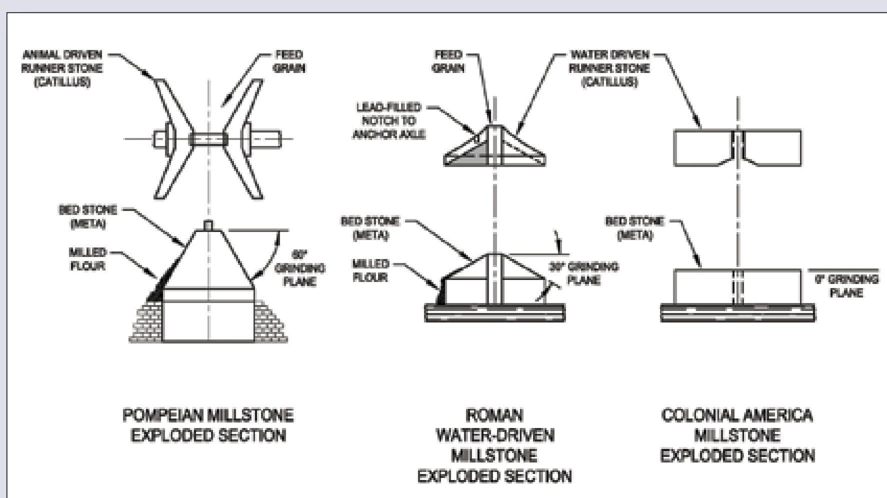
Both animal- and hydraulically-driven millstones were generally composed of two pieces (see the figure below). There was a top movable stone, known as a runner stone or *catillus*, and a bottom stationary stone known as a bed stone or *meta*. The runner stone was supported 1mm to 2mm above the bed stone, and the entire assembly was generally situated on a stone or timber base.

Grain was fed into the millstone assembly via a hopper located on the top of the runner stone. This hopper was shaped roughly like a funnel, facilitating a constant supply of grain to the millstone. In Pompeian-type mills, the hopper was built into the runner stone, forming a hollow, hourglass shape.

The hourglass Pompeian-type millstones typically have grinding-plane surface angles of 60 degrees to the horizontal, and were operated at a relatively low speed of probably three to five revolutions per minute. The centrifugal force at this rotational speed is negligible. Therefore, the grinding plane needed to be at a great-enough angle to rely on the force of gravity to eventually drop the grain to the bottom of the runner stone and exit.

A surviving preserved Barbegal bed stone has a straight, linear grinding-plane surface angle of approximately 30 degrees to the horizontal. This stone is similar to other Roman water-driven millstones that have grinding planes from 10 to 30 degrees. From Late Antiquity to the Middle Ages, typical water-driven millstones evolved to flat grinding-plane surfaces. Therefore, the Barbegal millstones show an intermediate step between the more conical earlier millstones and later stones that are essentially flat.

More importantly, with the advent of water power and gearing, the millstones were able to be operated at a much higher rotational speed – 10 to 20 (or more) times the rotational speed of an animal-powered millstone. Thus, because centrifugal force acting on the grain to push it from the centre of the millstone is dependent on the square of the velocity, and the centrifugal force of a water-powered millstone is several hundred times greater than that of an animal-powered millstone, a high angle on the millstone became unnecessary. Barbegal, therefore, may well have been responsible for the introduction of flatter millstone grinding-planes.



ABOVE Schematic side view of millstone function and evolution, illustrating the differences in millstone engineering.

Barbegal today

The Barbegal watermills lie at the entrance to the Vallée des Baux, 4km (2.5 miles) south of Fontvieille and 7km (about 4.5 miles) east of Arles. Les Alpilles, a low mountain range, runs along the northern border of the valley, with the stony plain of the Crau to the south. The site itself lies on a limestone ridge that rises about 30m above the valley floor.

Remains of the aqueduct that brought water to the mills are visible at several sites along its route, and show that it was built to a standard design with channel widths ranging from 0.6m (2ft) to 1.2m (4ft), and there are several Roman arch bridge crossings and tunneled sections. What remains of the Barbegal watermills can be seen on the south flank of a limestone ridge just off Route D82 (Route de l'Aqueduc) some 3km (about 2 miles) south-east of the village of Fontvieille. The entire foundation of the structure is still evident, and the walls of the waterwheel channels and mill rooms are still intact in places to a level of up to several metres.

The cornerstone of many great civilisations is their ability to sustain their population and feed their armies. The millstones of Barbegal tell a story of technological advancement and discovery that not only enabled the Roman Empire to do just that, but the innovations had a profound and lasting impact on the industrialisation of food production in the ancient world. ◘

RIGHT A remnant of a basaltic-rock-type millstone.

BELOW The Barbegal Aqueducts have several surviving Roman bridge arcades. This arch is located 200m (656ft) to the north of the mill site.

SOURCE Wayne F Lorenz is the Director of Roman Aqueduct Studies for the Wright Paleohydrological Institute (WPI), Denver, Colorado, and President of Wright Water Engineers, USA. He is also co-author of 'The Millstones of Barbegal', *Civil Engineering*, 2007; *wlorenz@wrightwater.com*.