A SIXTH CENTURY WATER-POWERED SAWMILL AT JARASH

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In his poem *Mosella*, written in the fourth century AD, Ausonius [a Gallo-Roman poet] says:

"...as to the other river (the Erubrus, now known as the Ruwer, a tributary of the Mosel near Trier, Germany), turning the mill-stones with rapid, whirling motion, and drawing the creaking saws through smooth white stone, listens to an endless uproar from each of his banks" (362-364).

These lines, apparently written in AD 367, have caused a lot of ink to flow (see, for general comments and bibliography, Wikander 1981: 91-104; 1989: 185-190; 2000: 401-410). The use of waterpower for grain milling is well known, from texts and numerous archaeological remains, all over the Roman World, at least from the beginning of the Christian Era in the Near East (for a general overview, see for example Humphrey, Oleson and Sherwood 1998: 29-34). On the other hand, archaeological remains that could be attributed to such an early use of waterpower for sawing wood or stone had, until now, been entirely unknown. Nevertheless, some scholars proposed theoretical reconstruction of "possible" mechanical sawing machines from Antiquity, based mainly on the assumption that "...restoration of an oscillating saw would require use of the crank, for which there is little evidence in antiquity..." (Humphrey, Oleson and Sherwood 1998: 34).

This *a priori* led some scholars suppose the use of circular saws, fixed either directly on the axle of the wheel of the mill (Landels 1978: 25), or moved by a system of sprocket wheel and gear overdrive. These reconstructions raise a lot of objections, of which one of the most obvious relates to the possibility of manufacturing iron discs of very large diameter (more than 2m), low thickness (2-3mm), perfectly circular and flat, and hard enough to resist a minimum of wear over time (profitability). In such a device, it would also be necessary that the stone blocks to be sawn are fixed on a mobile frame able to move in a regular and perfectly controlled way along an axis rigorously parallel to the plan of the saw. Such devices, mechanically and technically very complex, came into existence only recently.

To overcome this difficulty, other authors, like D.L. Simms, proposed the use of a continuous wire saw (Simms 1983). Even if one does not consider the problems raised by the mechanical parts of such an installation (see for example the far from convincing drawing published by Simms 1983: fig. 1), nor those related to the problems of driving the wire blade (profiles of the pulleys, friction and adherence to the driven pulley, tension of the wire, etc.), the simple manufacture of a loop without a visible connection (knot or welding), several meters in diameter, from a resistant wire whatever its nature, of 2-3mm maximum thickness, was not possible in Antiquity. Let us recall simply that this technique today uses high resistance steels (completely unknown in Antiquity), in the form of helicoidal wire or with built-in diamond teeth, and is employed only for the cutting of soft to semi-hard stones.

The technical difficulties raised by the two preceding systems led other authors, like P. Rosumek, to consider the use of a pendulum saw moved by means of a crank (Rosumek 1982). In spite of its apparent simplicity, the machine imagined by Rosumek calls upon many mechanical elements: pinions, axles, eccentric, etc. and supposes the use of a pendular saw, the point of suspension of which should be able to change, in a controlled way, in the course of sawing. The technical aspects of such an installation are not approached in detail, nor is the problem of guidance of the saw or that of the articulation saw/crank, which is essential to ensure the correct operation of sawing.

However, for the majority of the specialists of Antiquity, even to the above-mentioned authors, none of the proposed hypotheses appeared convincing. Their doubtful position seemed all the more justified since no undisputed remains of a water-powered sawmill dating from Roman times were known (some traces of such a possible installation, dating to the seventh/eighth century had apparently been found at Ephesus but were never fully published). Most of them reached the conclusion that Ausonius *Mosella* description was most probably a poetic allegoric form, far removed from a simple description of some real antique mechanical device.

A Seventy-Year-Old Unknown Discovery

"In 1926,... Mr Horsfield... converted a large supporting vault under the south side of the Artemis *temenos* into a museum for the permanent preservation on the site of inscriptions and other portable objects." (Kraeling 1938: 4). It was apparently during that "preliminary restoration" programme, undertaken at Jarash (جرش) before the joint British School of Archaeology in Jerusalem and Yale University archaeological research campaigns started, that the eastern end of the southern supporting vault of the sanctuary of Artemis was cleared. At the southeastern corner of the *cryptoporticus* a small room, partially opened up at that time, revealed the remains of a water-powered installation of some kind, which had never been published, nor apparently described. Since that time, the area was used as a store for inscribed stones collected on the site and the different remains from the water installation were progressively covered by stone blocks of all kinds and sizes **(Fig. 1)**. Despite this, the surviving remains form a coherent whole, "discovered" during the Gerasa antique water supply survey program we started in 2000, and can be clearly interpreted. Our thanks go to Dr. Fawwaz Al-Khraysheh, Director-General of the Department of Antiquities of Jordan, and to Dr. Roberto Parapetti, Director of the Italian Mission for the Study of the Temple of Artemis, who gave us permission, support and information to study this find. Our thanks go also to Suzanne Kerner, David Graf, Jean-Louis Paillet and Andrew Wilson for their help in collecting references (with special gratitude to the last who also kindly suggested some corrections to the English version of the text).

Coming from the courtyard of the Temple of Artemis, a double water channel (the source of which is actually unknown but was surely connected to the main aqueduct of the city) fed two large connected cisterns that are currently in a very ruinous state (Fontana 1986: 182, structures A and B in fig. 7). The small one, to the south, served as the header-tank for a water installation located nearly four meters below in the southeast corner subterranean chamber of the sanctuary. The side walls of the vertical and horizontal water channels are still preserved, as are the positions for the bearings for an horizontal shaft placed over the lower channel **(Fig. 2)**.

During the 1930's excavations, the American archaeologists found in the same room of the southern Artemis Temple underground gallery, on either side of the tailrace, two hard limestone column drums that had been partly sawn. These drums are currently stored against the walls of the underground room.

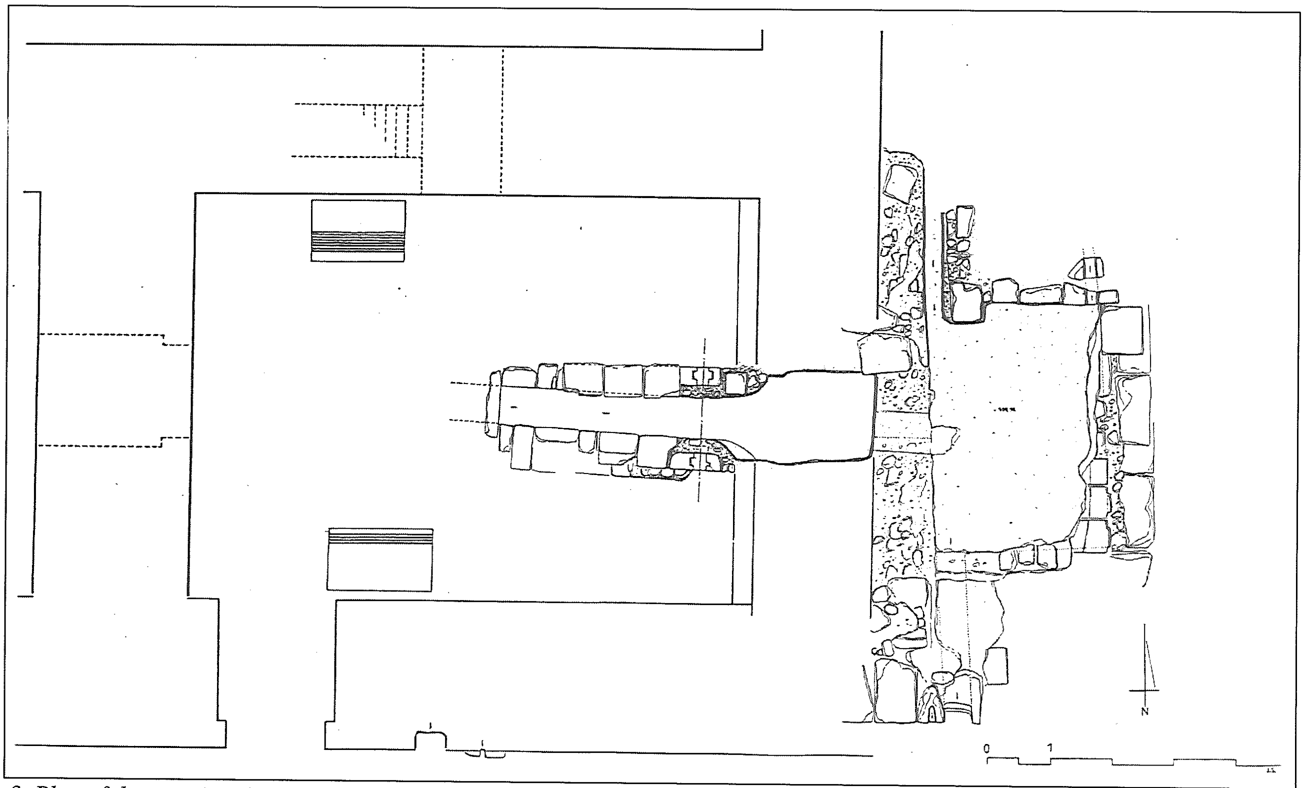
2. The head race and wheel race. Actual state.

1. General view from the west. Actual state.

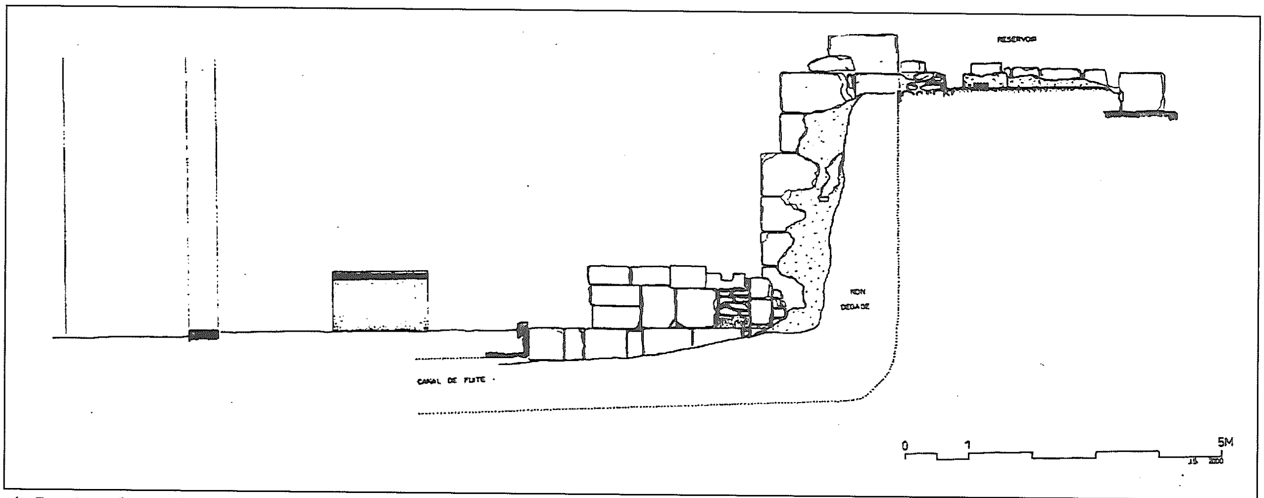
Remains of a Water Mill

The installation occupies a rectangular chamber of 8.65m length and 6.65m width, originally covered by a barrel vault. In the middle of the western wall, an axial door, 1.51m wide, gave access to all the other underground rooms of the *cryptoporticus*. In the southern wall a second opening of the same width (1.52m), offered direct access from the street skirting the southernmost frontage of the sanctuary. The inner floor of the room lies at about 3.80m below the level of the water tank floor. Inside the room, the surviving remains of the hydraulic installation include **(Figs. 3, 4)**:

- the head-race, vertical channel, ±1.35m broad by ±2.30m deep, perforated through the thickness and in the middle of the eastern wall. It was probably built at the place on an old opening. Its walls are still covered with a thick coating of pinkish mortar. Most of the filling of the channel is still *in situ* and could be excavated;
- the ±0.60m broad wheel race, covered in its western part, was not fully excavated. Its depth remains unknown;
- the walls of the wheel race are still *in situ*, completely preserved. They are built of large reused blocks of hard limestone fixed with lime mortar.



3. Plan of the remains. Actual state (J.S.).



4. Section through the head race and wheel race. Actual state (J.S.).

The rectangular carved places, planned for the embedding of two bearings for a shaft of a waterwheel, are perfectly visible on the "waiting beds" of two of them **(Figs. 2, 3)**. The external face of the southern one carries, very distinctly, the circular traces caused by the friction of an "object" whose dimensions can be estimated (see below and **Fig. 5**). These marks enable us to know further that the position of the horizontal shaft of the wheel of the mill was modified during the machine's life (lowered or heightened by ±0.14m);

- the outlet channel was not explored. It seems to have flowed along the axis of the room. It probably runs under the threshold of the eastern door before turning south to join the main sewer of the street. As for the wheel race, it remains to be excavated.

The visible archaeological remains suggest that there was formerly a bucketed waterwheel, about 0.50m wide (maximum) and with a diameter of between 4.00 and 4.50m, with an horizontal shaft. The absence of any piece of millstone and, above all, the fact that the two shaft bearings, placed directly on the top of the millrace walls, are immediately on either side of the waterwheel exclude the possibility of a grain mill (in such a mill, the wheel-shaft bearings would be spaced asymmetrically on either side of the waterwheel to allow for the pit-wheel and the gearing for turning the millstones). The lack of any trace in the walls of the chamber or elsewhere of any other bearing confirms this interpretation. Further, circular wearmarks on the exterior surface of the southern millrace wall show that something (probably a wooden disc built up with iron nails), of at least 1m diameter as shown by the traces, was fixed at either end of the wheel-shaft **(Fig. 5)**. From all these archaeological evidences, we may conclude that an overshot waterwheel was mounted on a short horizontal shaft with two vertical wooden(?) wheels, one at each end of the shaft.

Two Partly-Cut Column Drums

Two drums of columns (n° 1 and 2) were found by the American archaeologists in the western part of the room **(Fig. 3)**. They are currently stored against the southern wall (block 1) and the northern wall (block 2), positions that strongly suggest they were originally found on the right and left side of the tailrace. They are the only two uninscribed architectural fragments visible in this room which is used as a temporary epigraphic store by the American excavators. Both column drums originally came from the porticoes of the Temple of Artemis and were abandoned when they had been only partly sawn. They are similar in size, both about 1m in diameter, and with lengths of 1.67m and 1.51m respectively. The block n° 1 has four saw-slots penetrating to the same depth even though the outer surface was curved **(Fig. 6)**. The block n° 2 has two groups of four saw-slots, separated by four preparatory cutting lines. The four saw-slots of each of the two groups penetrate to the same depth, and the width of each partly-cut slab is similar **(Fig. 7)**.

The various traces visible on the two column drums can only be explained by the use of a group of four saw blades, separated by a few centimetres and working simultaneously.

The presence inside the chamber of the two drums, each weighing more than 2 tonnes, shows that they had been brought there intentionally, which strongly suggests that their conversion into thin slabs could not have been carried out elsewhere.

All the preceding archaeological data lead to the conclusion that there was a direct connection between the water-powered installation and the hard limestone column drums being sawn. The water mill structures and other related archaeological remains found correspond, from all the evidence, to a powered sawmill: an overshot waterwheel would have been used for sawing large hard limestone slabs.

Reconstruction

The Saws

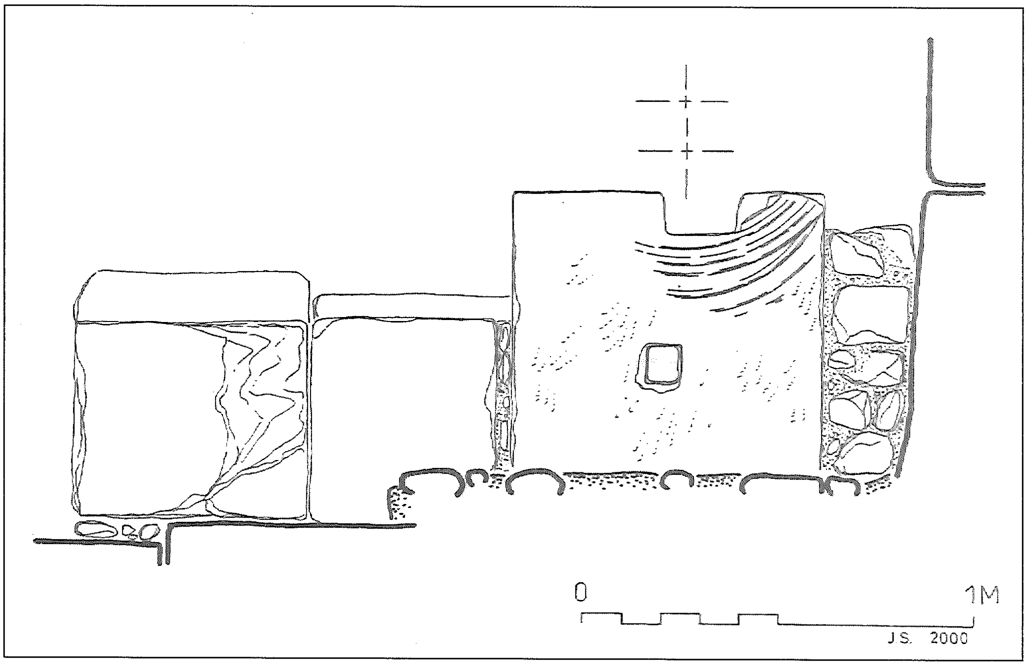
Saws used for cutting hard stone do not have teeth but are used with an abrasive material (such as sand or emery) and water that is applied to the work-surface by the pressure of the blade.

If the elements preserved *in situ* in the underground room of the sanctuary of Artemis do really belong to a mechanical sawing installation, the latter was surely not equipped with circular saws. This possibility is completely excluded: the technical problems mentioned above would have been even more complicated here by the need for assembling a group of four identical saw discs, in parallel, exactly of the same size and separated only by a few centimetres, at each end of the wheel's mill shaft. Moreover, the position of the water wheel inside the room, near the eastern wall, would have excluded any possibility of moving the blocks under the saw blades.

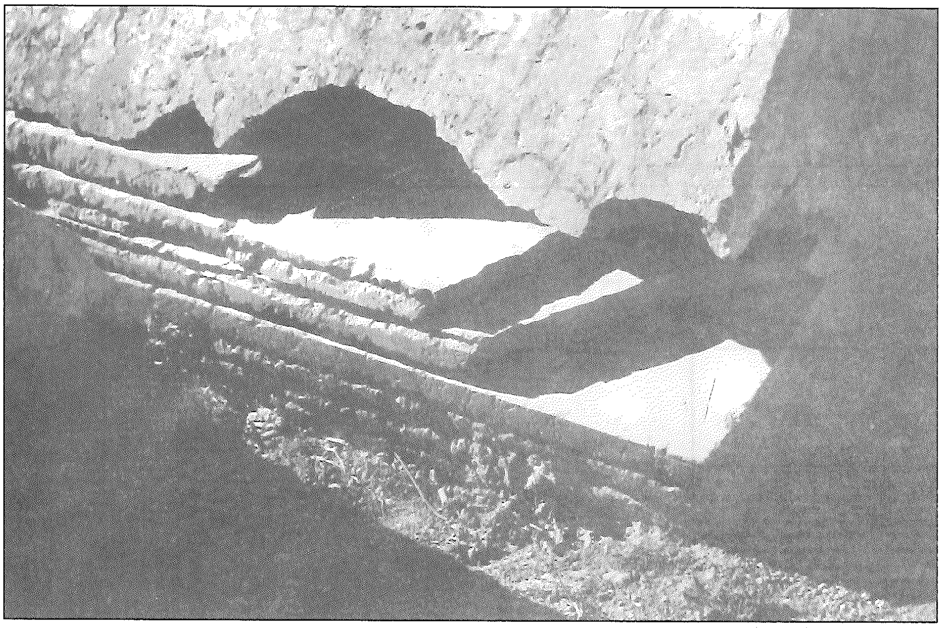
For similar technical reasons, the use of eight continuous wire saws working simultaneously is absolutely not conceivable.

All the archaeological evidence leads to the conclusion that the sawing tools were of the "traditional" framed type.

Traces visible on the partly cut columns drums show that the saws were multi bladed. The size of the blocks (1m in diameter and about 1.70m in length) implies that the saws had a minimal vertical race of 1.10m and a minimal blade useful length of 2.20m (length of the block plus a minimal working race of at least 0.50m). All these constraints result in restoring wooden frameworks carrying four blades each, their overall low size limits



5. Southern elevation of the wheel race showing traces of the outside "wheel" on the wall and the two successive positions of the water wheel axle (J.S.).

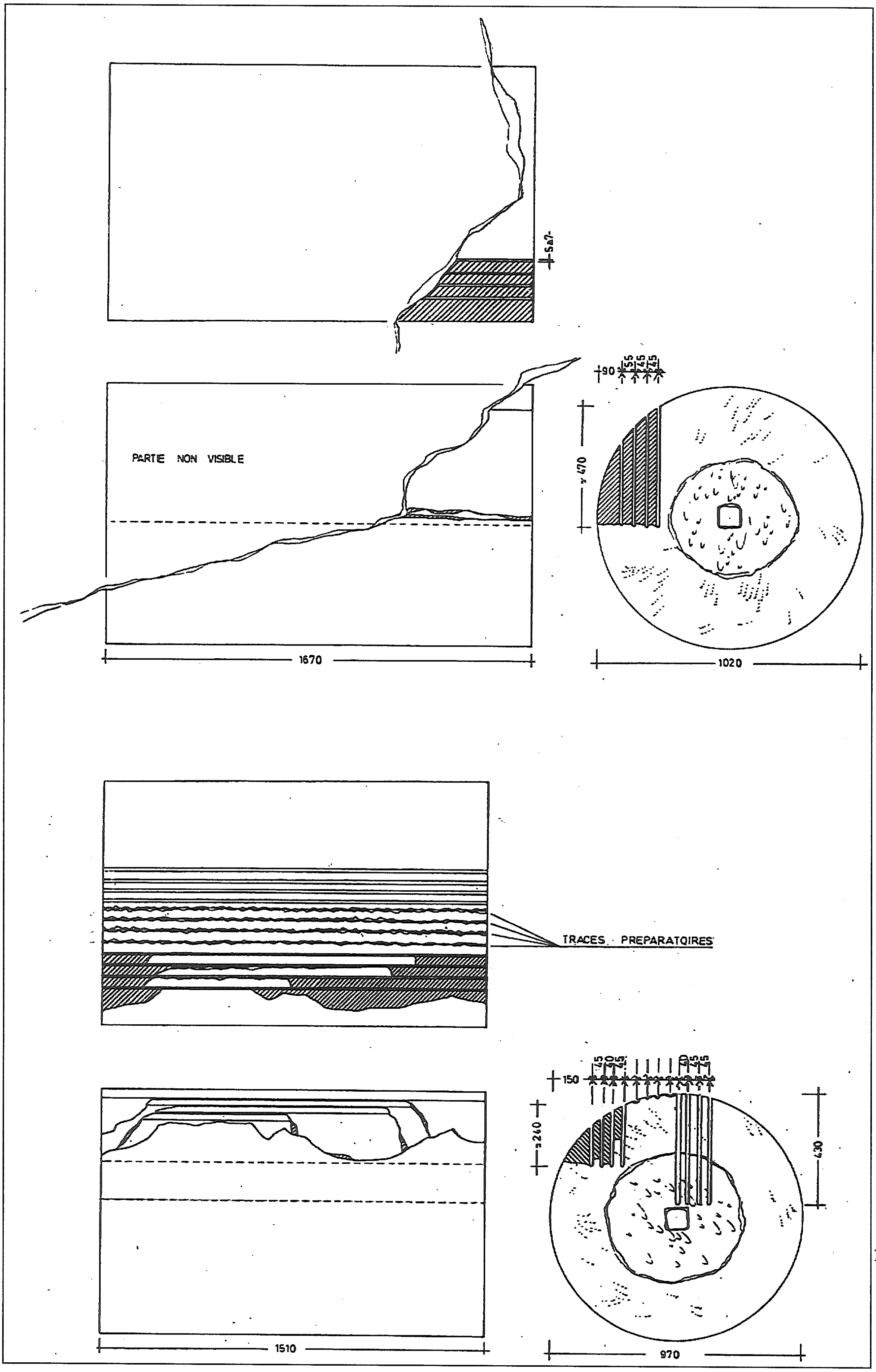


6. Column drum n° 2, detail.

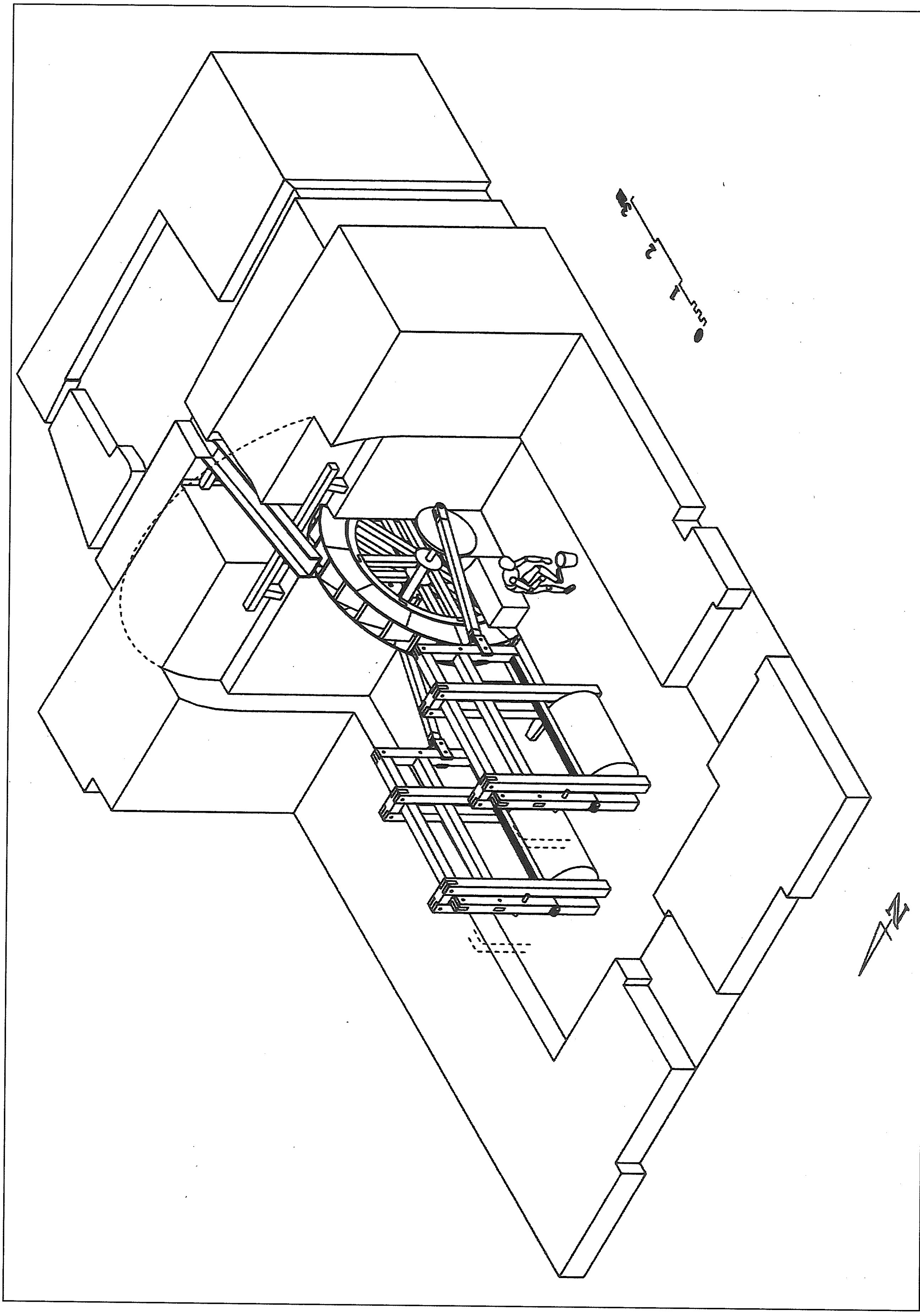
being ±2.60m in length, ±2.00m in height and ±0.20m in thickness.

The tension of the blade of a saw must be as perfect as possible. On a single blade framed saw, tension results from the torsion of a rope placed opposite to the blade. However, it is very difficult to forge strictly identical iron blades of more than 2.50m length. Because of their small difference in length, due to the artisan manufacturing techniques, in a multi-bladed saw each blade had to be able to be put in tension separately. This detail leads to the conclusion that the frame has to be a rigid one, the usual high tightening rope being replaced here by a piece of wood firmly pinned with the other pieces of the structure. The independent setting in tension of the blades could be carried out, for example, by small metal or wooden pieces, inserted on the level of the ends of each blade and the lower part of the rigid frame of the saw.

These saws must have cut vertically down through the stone, with the blades moving back and forth horizontally, so as to take advantage of their weight which can be estimated at ±300kg (0.35m^3 of wood or ±270kg plus ±30kg for the iron blades). Moreover, the size and the shape of the column drums as well as the places of sawing do not make it possible to imagine that these frameworks could be horizontal, except by giving them disproportional dimensions.



7. Column drums 1 and 2 (J.S.).



8. *Reconstruction of the installation (DAO: Thierry Morin).*

Lastly, the size of such tools and the perfectly rectilinear aspect of each cutting exclude the use of any pendulum device for the guiding and the handling of the saws. The weight and the size of the tools, as the perfect parallelism noted in the layouts of the sawing, result moreover in restoring a guiding device, maintaining the saws laterally during work, most probably by an external wooden frame fixed to the ground and/or to the walls. These guidance structures were also essential to lift up the saws at the end of the cutting. Resumption of archaeological excavation of all the room appears as absolutely necessary.

Mechanical Device

The archaeological remains make it possible to consider only a solution with a mechanical device ensuring the transformation of continuous circular motion, provided by the mill, into longitudinal reciprocating motion necessary for the correct operation of cutting stones with vertical multi-bladed framework saws. We thus should consider either a system with cranks or a system with eccentrics and connecting rods.

Whereas the remains of the installation are exceptionally well preserved, no other element which could be related to the installation described was found in the room. In particular, neither pit nor stage for low articulation of beam can be reconstructed on either side of the wheel race (this is absolutely necessary for a crank system device, see for example Diderot et d'Alembert 1751-1772: figs. 2 and 3 plate III, *Moulin à scier les pierres en dalles)*, although the built ground is mainly preserved in that place. In the absence of any archaeological remains which could be related to a crank beam, it is thus very probable that the mechanical installation did not call for a system with cranks, but with an eccentric and connecting rod. According to the evidence actually visible at the site, each of the wooden wheels — that one could infer without any great risk of error — were fixed at each end of the water wheel-shaft would have carried an eccentric metal pin. Long connecting rods would have linked the eccentrics to the end of the saw-frame **(Fig. 8)**. By using the two ends of the wheel-shaft, the whole assembly would be balanced and able to turn out simultaneously eight slabs of hard limestone, each of a very large size. The sophistication of the mechanism at Jarash shows that this was probably not just a prototype.

A 1500-Year-Old Sawmill

This workshop must be dated later than the fifth century AD, a time when the Temple of Artemis, abandoned as a place of worship, was used as a "stone quarry" for the construction of Byzantine monuments. Only at that time could columns from courtyard porticoes have been dismantled and reused as material for stone slabs. It must however date from before 749 when a great earthquake completely destroyed Jarash and led to its progressive abandonment.

It is possible to be more precise: the construction of such a water-powered workshop could only have been undertaken at a time when the technology and the necessary capital were available and when there was a strong demand for stone slabs. Pending a resumption of the excavation work and more detailed study of the ruins, one might propose that construction of this water-powered site probably took place at the time of Justinian (AD 527-565) and his immediate successors, a period of relative prosperity in Jarash when more than twenty churches and chapels as well as bath houses were built, all great consumers of stone slabs for floors and walls. If this dating is confirmed, then the water-powered workshop at Jarash preceded by more than six hundred years the oldest water-powered sawmills currently known.

The discovery at Jarash, of a water powered installation which could be related to a mechanical stone saw mill, shows that the utilisation of the eccentric, in a highly developed form with connecting rods, may date back at least to the sixth century AD in the Middle East. It is thus possible that in the fourth century AD, Ausonius really did see on the banks of the Mosel, not far from Trier, mills "...driving strident saws across blocks of marble...".

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