A ROMAN WATER-MILL IN THE ATHENIAN AGORA

In 1933, in Section Iota, just south of the Stoa of Attalos, a long stretch of the so-called Wall of Valerian was uncovered, with two towers projecting towards the west.[1] Here, in the sunny southwest corner where the northernmost of the towers makes an obtuse angle with the west face of the wall,[2] an unpretentious but curious building was revealed.

A great slot-like structure was found first: long, narrow, set deeply into the bedrock[3] (Fig. 1, A and Fig. 6). Its walls were thickly coated with lime deposit, left by the hard Athenian water. From the foot of its north wall, a drain of considerable size had served to carry off the water towards the north (Figs. 1 and 2), but in all the three-metre height of the south wall there was no trace of an inlet of proportionate size (Fig. 3). In the west wall an arched niche rose above a ledge which ran the length of the slot. The niche was floored with a block of marble with a rectangular cutting, like a socket, in its outer edge (Figs. 2 and 4, *α*). Just opposite, in the east wall, an arched aperture (Figs. 3 and 5 A) opened into an adjoining room (Fig. 1, B; Figs. 6 and 7). This room, though bonded with the "slot" at the southwest corner, was of much more summary construction; and the lower courses of the "Valerian Wall" and the south wall of its tower had served as east and north walls of the building. The floor was covered in great part by a layer of carbon and ashes on which lay two circular mill stones, as well as fragments of several others.[4] In the floor, just inside the arch, was a rectangular

[1] *Hesperia*, IV (1935), pp. 329 ff.

[2] *Ibid.*, pl. III. The wheel-race and flume of the mill are shown with a broken line.

My indebtedness for assistance in preparing this study is gratefully acknowledged to the following: Professor A. W. Van Buren who called to my notice a Roman mill-wheel in the Naples Museum and a Roman water-wheel in London; Cav. Ing. Luigi Jacono who supplied me with a photograph of the Naples wheel and a most helpful accompanying letter; the authorities of the British Museum, particularly F. N. Pryce, Esq., who sent me information about the London wheel and saw that I was supplied with photographs; André Kenny, Esq., of Trinity College, Cambridge, who generously placed at my disposal his expert knowledge of ancient hydraulics and made many useful suggestions; Col. R. W. Gaussman, general manager of the Athens Water Supply Works, whose wide experience and practical knowledge helped solve many a puzzling problem; and finally, my colleagues, H. A. Thompson and J. Travlos, the latter of whom has prepared all the drawings for the article.

[3] The maximum dimensions preserved are: Length, 5.50 m.; width, 1.10 m.; height, 4.20 m. Levels where given in the drawings are in metres above the floor of the drain north of the mill (cf. Fig. 1).

[4] The dimensions of the room are roughly 7.00 m. × 4.60 m. Like the slot, the room was sunk into the bedrock, but less deeply; while the floor at the south is *ca.* 0.80 m. below bedrock level and 1.70 m. below the ancient ground level, the slope is such (Fig. 1) that at the north the depth is very slight. The shabby wall of rubble in the southeast corner (Fig. 6) is merely a facing for the bedrock exposed below the foundation of the "Valerian Wall."

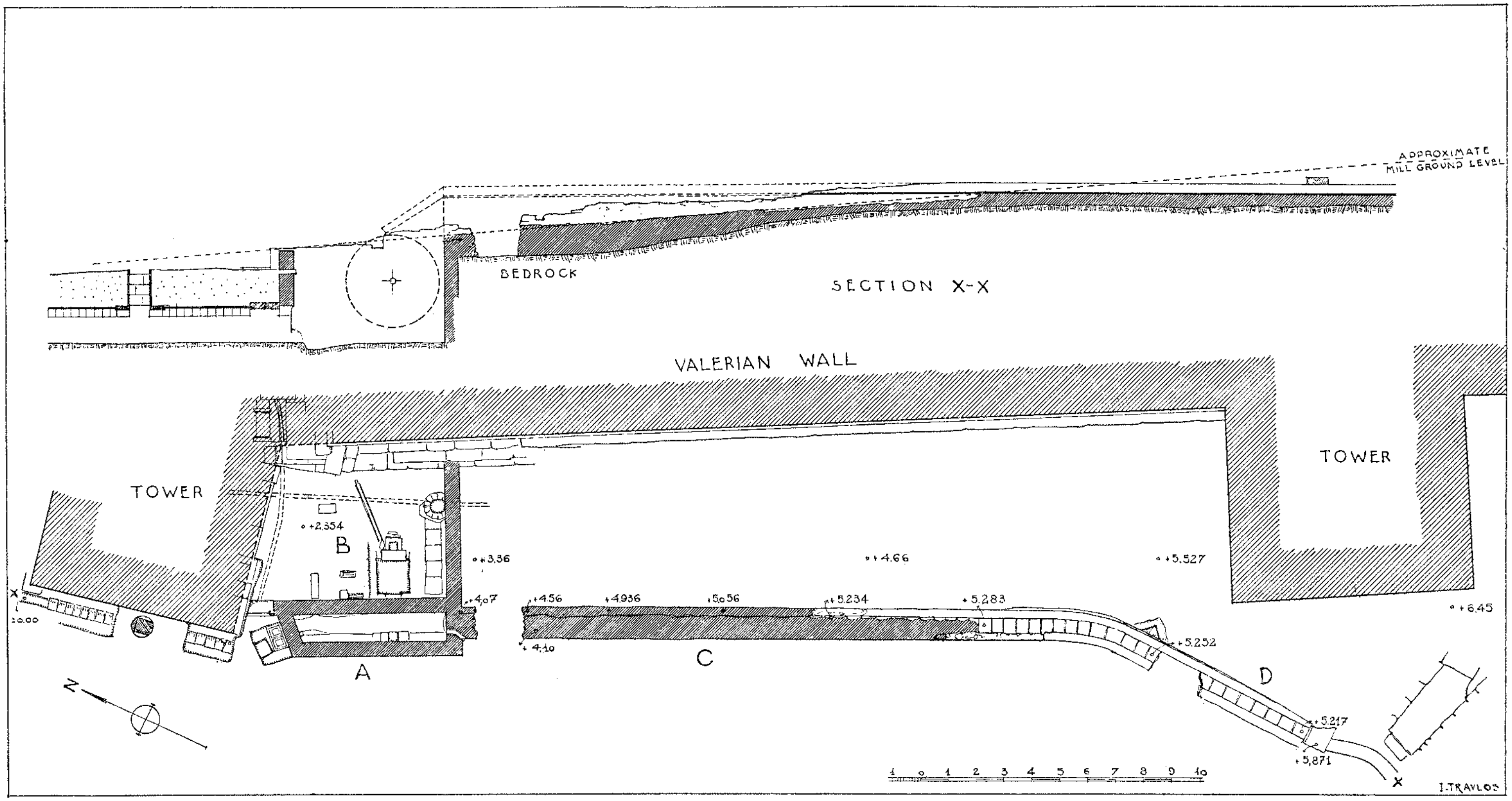

Fig. 1. Plan and Longitudinal Section of Mill and Mill-race

Fig. 2. West and North Walls of Wheel-race, from South

Fig. 3. East and South Walls of Wheel-race, from North

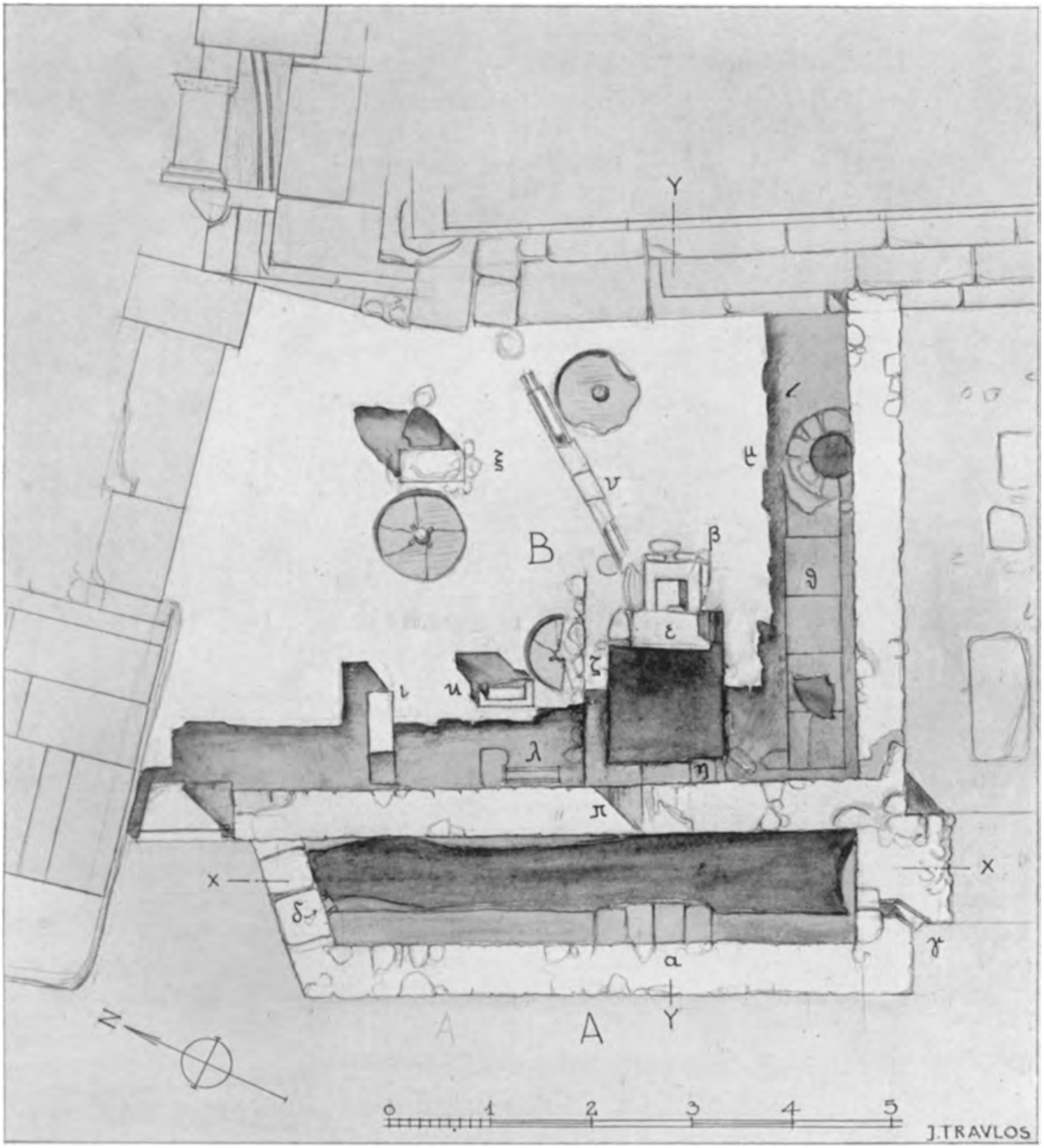

Fig. 4. Plan of Mill-room and Wheel-race, Actual Condition

pit with built-up sides and a heavy wall of large blocks at its east end (Figs. 5 B and 8); here was a second block of marble with a rectangular cutting, apparently corresponding to that in the niche (Fig. 4, *β*).[1]

The stones lying on the floor and the socket-like cuttings suggested the character of the building. But the complete interpretation was not clear until further excavation showed, first, that a massive but considerably broken wall running towards the south from the end of the slot had originally been bonded to—an integral part of—the slot (Figs. 1, C and 6),[2] and then that a carefully built water-channel previously exposed some 20 m. to the south had once been carried all the way north on this wall (Figs. 1, D and 9).

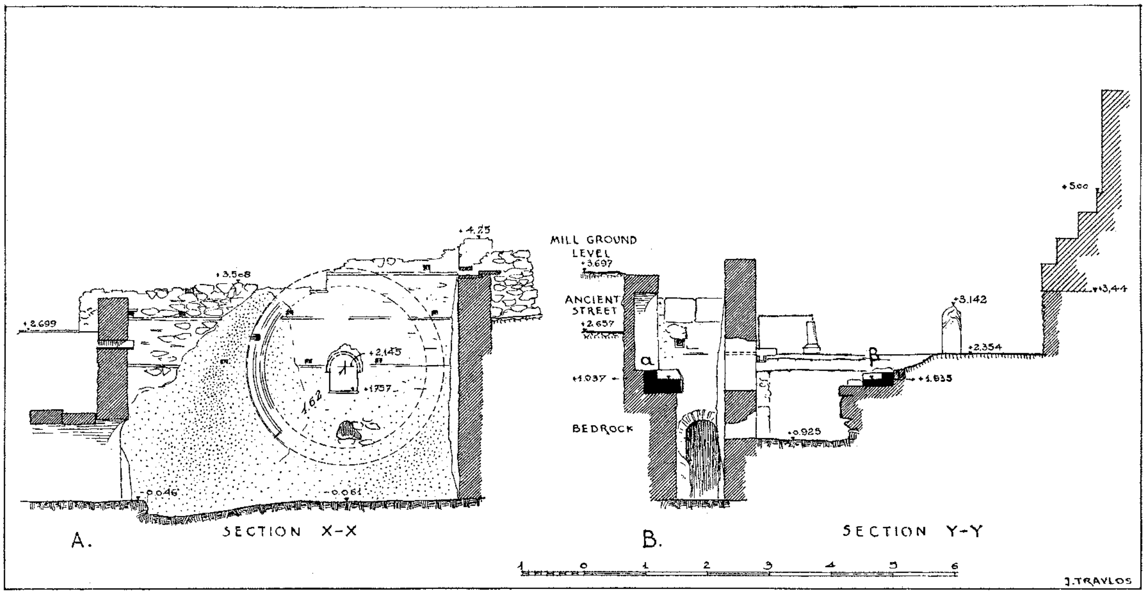

Fig. 5. Longitudinal and Cross Sections

No further question now remained as to its identity; no one familiar with the mills which are today a picturesque and charming feature of the Greek countryside, wherever there are streams copious and permanent enough, could fail to be struck by the similarity, in every essential detail, between this simple structure of the late Imperial period and the only slightly more elaborate installations of modern times. The entire complex could be nothing but a flour-mill, powered by water.

[1] The pit is *ca.* 1.15 m. long, *ca.* 1.10 m. wide, and *ca.* 1.40 m. deep. Its floor is formed by the rough bedrock. The wall below the arched opening is pierced, at the level of the floor of the pit, by a runout hole (Fig. 5 B) apparently made after the wall was built when it was found that water collected in the pit. The "socket" shows plainly in Figure 7, and in Figure 8 in the foreground.

[2] The wall was completely destroyed just south of the slot by a well sunk in the Middle Ages.

Fig. 6. Mill-room and Wheel-race from Northwest

Fig. 7. Mill-room and Wheel-race from Northeast

No other mill of this type, preserved from antiquity, seems to have been found, or, if found, to have been published,[1] although the existence of the ὑδραλέτης in many parts of the ancient world and over a long period of time is well attested in literature.[2] But Vitruvius' account of how a water-mill is to be built is, despite its brevity, sufficient to show that the Agora mill is as close to the ancient tradition as to the modern.

These are the relevant passages from the *de architectura*:

(X, 4, 1) ... Et primum dicam de tympano ... ad tornum aut circinum fabricatus ⟨axis⟩, capitibus lamna ferratis, habens in medio circa se tympanum ex tabulis inter se coagmentatis, conlocatur in stipitibus habentibus in se sub capita axis ferreas lamminas ...

(X, 5, 1) Fiunt etiam in fluminibus rotae eisdem rationibus, quibus supra scriptum est. Circa earum frontes adfiguntur pinnae, quae cum percutiuntur ab impetu fluminis, cogunt progredientes versari rotam ...

(X, 5, 2) Eadem ratione etiam versantur hydraletae, in quibus eadem sunt omnia, praeterquam quod in uno capite axis tympanum dentatum est inclusum. Id autem ad perpendiculum conlocatum in cultrum versatur cum rota pariter. Secundum id tympanum maius item dentatum planum est conlocatum, quo continetur. Ita dentes tympani eius quod est in axe inclusum, inpellendo dentes tympani plani cogunt fieri molarum circinationem. In qua machina inpendens infundibulum subministrat molis frumentum et eadem versatione subigitur farina.

The mill has been badly destroyed; its walls are standing, roughly, only to the ground level contemporary with the destruction (Fig. 1) but, thanks to the fact that its floor level was far below that of the ground outside, an unusual number of details are preserved. So many, indeed, that the temptation to try a reconstruction, using the text of Vitruvius as a basis and the analogy of modern mills as an aid, is too great to be resisted.

If for the *flumen* we substitute the great slot, setting the wheel, the *rota*, here, we have the Vitruvian scheme exactly. The *axis* runs between the sockets, from the niche

[1] Scanty traces of water-mills have been found on the Janiculum in Rome (A. W. Van Buren and G. P. Stevens, *Memoirs of the American Academy in Rome*, 1915–16, pp. 59 ff., and *ibid.*, 1933, pp. 69 ff.). There must have been a water-mill at Venafrum, where the Naples wheel was found. The wood had entirely decayed but had left its impression in the heavy incrustation of lime which had formed about it; enough of this incrustation is preserved to permit reconstruction of a wheel of Vitruvian type with *pinnae*. The wheel, restored in wood, is now in the Technological Section of the Naples Museum, but is, as yet, unpublished.

[2] The important collections of source material on mills are these: Blümner, *Technologie und Terminologie ... bei Griechen und Römern*, I (1875), pp. 23–49 (water-mills, pp. 45–49); L. Lindet, "Les origines du moulin à grains," *Rev. Arch.*, XXXV (1899), pp. 413–427, and XXXVI (1900), pp. 17–44 (water-mills, *Rev. Arch.*, XXXVI, pp. 35 ff.); Baudrillart, art. *Mola*, in Daremberg-Saglio, *Dict. des Antiquités* (water-mills, pp. 1961 f.); A. Hug, art. *Μύλη* in Pauly-Wissowa-Kroll, *Real-Encyclopädie*, XVI (1933). Blümner's article is basic, particularly for the technical aspects and the terminology. Lindet's is the most historical in its approach, as the title implies; but much can still be done with the history and still more could be done were excavators to overcome their reluctance about publishing millstones found on ancient sites. A reference to Kourouniotes, *Ἀρχ. Ἐφ.*, 1917, pp. 151 ff., would be in place in Hug's article, following his citation (col. 1071, top) of Versakis, *Ἀρχ. Ἐφ.*, 1914, pl. I. An interesting recent addition to the source material is the epitaph of a *μαγγανάρειος ὑδραλέτα* of the 4th or 5th century A.D., from Sardis (Buckler-Robinson, *Sardis*, VII, *Greek and Latin Inscriptions*, I, 1932, pp. 138 f., no. 169).

in the wheel-race to the far end of the pit in the mill-room (Fig. 5 B, α and β). On the shaft where it crosses the pit must be set the vertical *tympanum*, meshing[1] at the top with the larger[2] horizontal *tympanum*. The vertical shaft on which this is fixed will, in turn, move the mill-stone on a platform above.

These are the main outlines; something more can be made from a detailed examination (Fig. 10). First the wheel-race: its walls are stoutly built of rubble and mortar, with courses of brick at intervals of *ca.* 0.75 m.[3] Its unpaved floor is deep below the ground level, so that the socket for the axle-bearing, 2.10 m. above, may be firmly braced against the bedrock. The ledge, or catwalk, is wide enough for a man to move about on in comfort, if he supports himself with his hand against the opposite wall. The arched recess is high enough and deep enough for a man to crouch in and have room to work at the bearing. The catwalk could be reached without great difficulty from the north end of the race, which was apparently never built higher than the two large blocks which now crown the wall. At either end of the wheel-race a small drain opening from the street level helped to keep the ground outside the mill dry (Fig. 4, γ, δ; and Fig. 5 A).[4]

Fig. 8. The Pit from the East; the Western Socket shows beyond the Arched Opening

[1] This is surely the meaning of *quo continetur*, and makes it unnecessary to assume that something has been lost from the text.

[2] This seems the easiest and most natural interpretation of *secundum id tympanum maius* . . etc. In the Agora mill, at least, there is reasonably sound evidence that the horizontal gear was the larger.

[3] On the brick courses rested the crossbeams of the builders' scaffolding; the holes, still visible (Fig. 5 A), pass completely through the wall. This was, as it still is in Greece, the common method of supporting the staging (cf. a good illustration of such a scaffolding in a tomb painting of the late third century in Rome, *Arch. Anz.*, 1912, p. 293, fig. 14). The walls themselves are *ca.* 0.50 m. thick, bound with a strong mortar.

[4] The small drain which empties into the wheel-race through the north wall was certainly intended, originally, to catch and carry off the water which would otherwise have run from the higher level of the street down to the door of the mill-room. The drain which discharged into the southwest corner of the mill-race just at the level of the street, unquestionably represents an already existing channel which was cut off by the construction of the mill.

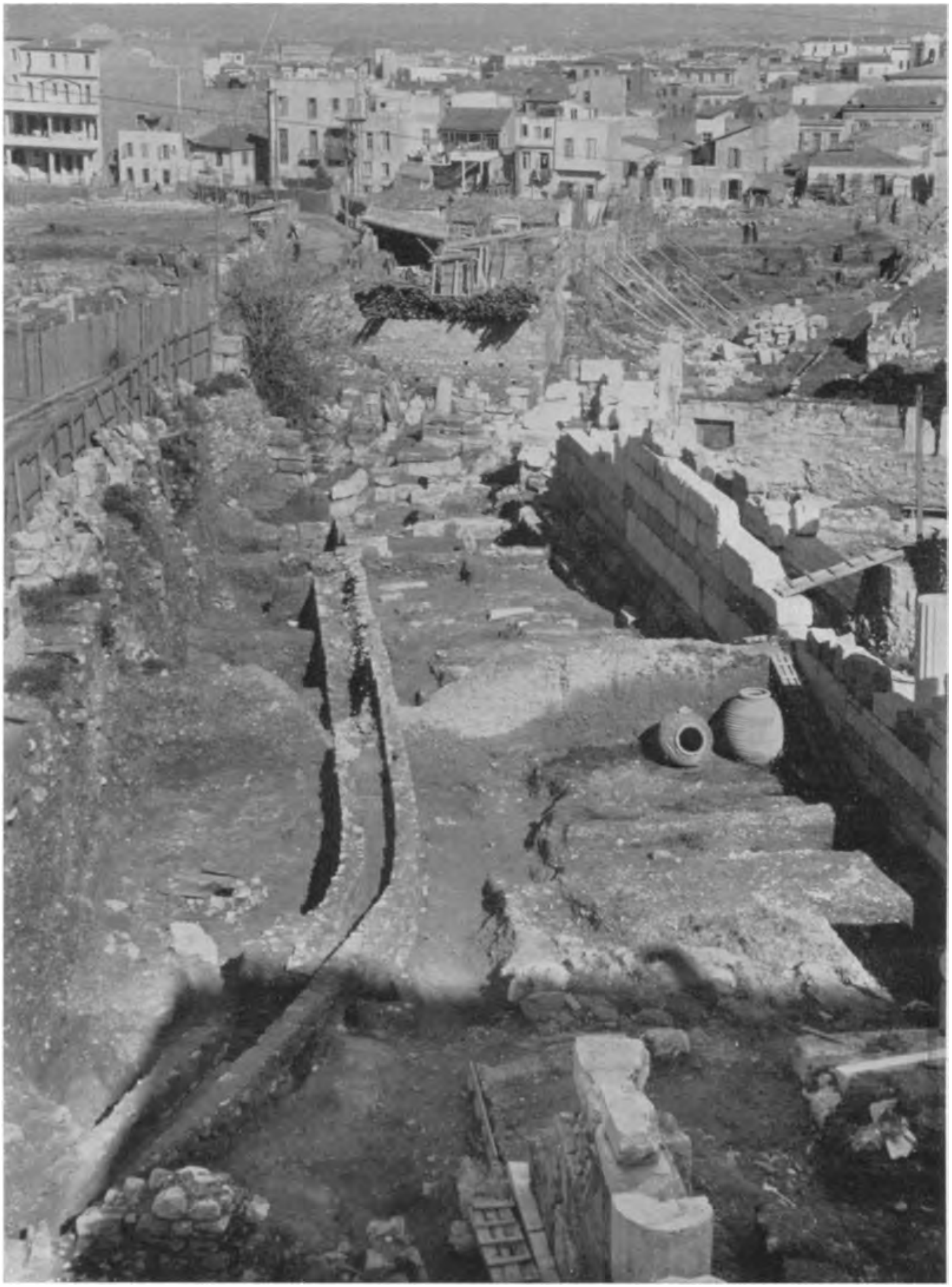

Fig. 9. General View of Mill-race and Mill, from the South

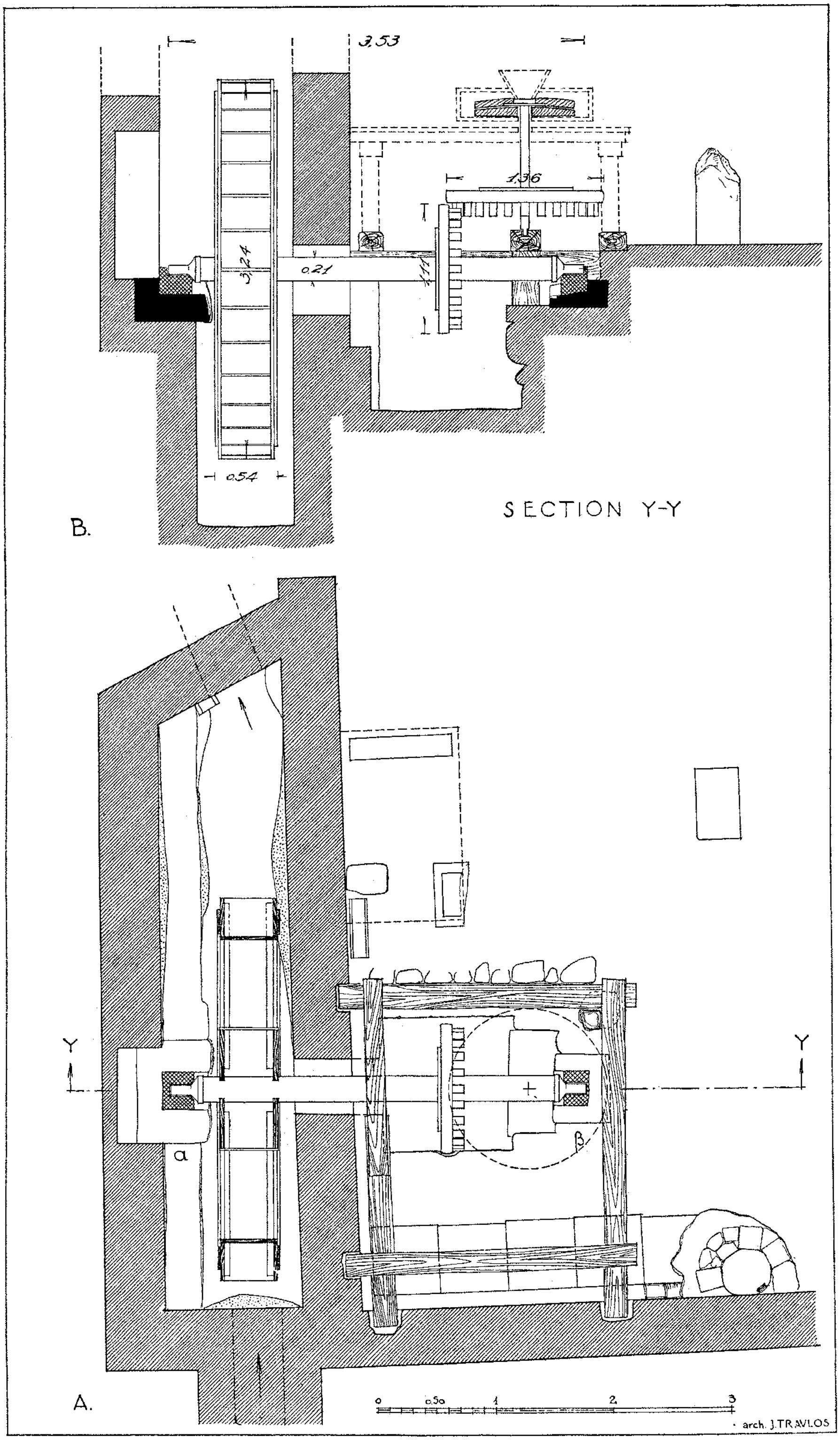

Fig. 10. Restored Plan and Section

The most interesting feature of the wheel-race is the evidence it offers as to the nature and size of the wheel itself. Here, two things help: first, the way in which the lime deposit has formed on the walls shows at once that the wheel was overshot, i.e. that the wheel, as seen in elevation from the west (Fig. 5 A), received the impulsion of the water on its upper left perimeter and turned in a counter-clockwise direction. Only if this were the case could the deposit have formed as it has, most thickly and evenly along the left perimeter of the wheel and down to the floor of the race, and again in great, irregular blobs at the lower right where the last drops were kicked off (Figs. 3 and 5 A).[1] Secondly, a builders' blunder which was undoubtedly a sad inconvenience in antiquity has proven a boon to the modern student. A straight-edge laid on the plan (Fig. 1) will show that the axis of the flume falls just a little out of line with

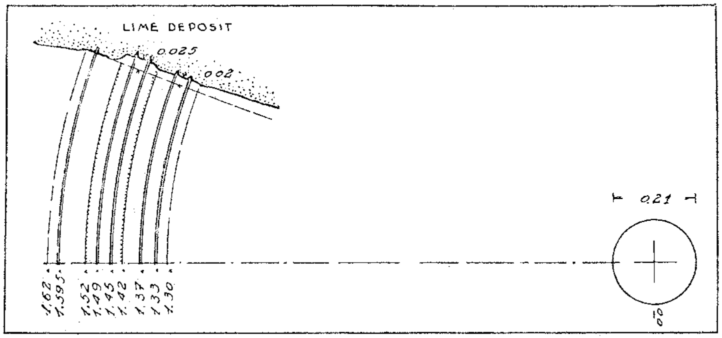

Fig. 11. Profile and Projection of Scratches made by Wheel

that of the wheel-race. The divergence is not great but it is enough so that the wheel, in order that it might take the force of the water as squarely as possible, had to be set at a slight angle to the walls of the wheel-race. The result was that the rim of the wheel, swinging close to the east wall, has left plain traces in the heavy lime deposit, in the form of a series of concentric grooves (Fig. 3). Thus the profile of the wheel, for something over 0.30 m. back from the circumference, is perfectly preserved.[2] This enables us not only to determine exactly the diameter of the wheel—3.24 m.—but also to fix its centre with accuracy. Further, the clear marks of nails and of projecting planks which show that the rim was attached outside the spokes, not inside, as often in modern times, give us a hint of what may have been the actual construction of the wheel. The wheel will, naturally, have been of wood; its chief difference from that of Vitruvius being that since this is an overshot wheel we must substitute some sort of buckets for his *pinnae*.

[1] The lime deposit is indicated in Figure 5 A by stippling; where the dots are densest, the deposit is heaviest.

[2] Fig. 11 shows the profile of the rim as it is preserved in the lime deposit; the restoration in Figures 10 A and 10 B has, except in respect to its diameter and width, no claims to authenticity, and is shown simply

Just such a wheel as this it must have been which Antipatros of Thessalonika pictures, in a not unpleasing conceit, as turned by the leaping feet of Demeter's nymphs.[1] To it the water was brought through a nearly horizontal mill-race, just as it is done in many a modern mill (Figs. 12 and 13), with one striking difference. The modern overshot wheel is turned by the weight of the water alone; the water drops into the

Fig. 12. The Agora Mill-race looking North

Fig. 13. Modern Mill-race near Livadia in Boeotia

exempli gratia. The wheel in London may give some clue to the way our wheel was put together. It is not a mill-wheel but a wheel for raising water (Vitr. X, 4, 3) from a Roman mine in Spain. A similar wheel (from the same mine?) is illustrated by Ardaillon in Daremberg-Saglio, *Dict. des Ant.*, s. v. *Metalla*, figs. 5002 and 5003. Despite the difference in function, these wheels with their *modioli* (Vitr. *l. c.*) and their many long spokes, are in their general structure closer to what ours must have been than is the Venafrum wheel, that is small, chunky, and designed to turn rapidly in a fast-running stream.

1 *Δηὼ γὰρ νύμφαισι χερῶν ἐπετείλατο μόχθους·*
αἱ δὲ κατ' ἀκροτάτην ἁλλόμεναι τροχιήν
ἄξονα δινεύουσιν· ὁ δ' ἀκτίνεσσιν ἑλικταῖς
στρωφᾷ Νισυρίων κοῖλα βάρη μυλάκων·

Anth. Pal. IX, 418, vv. 3–6

The poet can only have been thinking of an overshot wheel; otherwise the picture suggested by *κατ' ἀκροτάτην ἁλλόμεναι τροχιήν* quite loses its point. The *ἀκτῖνες ἑλικταί* must be, of course, the teeth of the *tympana dentata*, as the editors of the revised Liddell and Scott point out.

buckets from but a hand's breadth above (Fig. 14). Only in the case of small undershot wheels or horizontal turbine wheels is the force of the water utilized by dropping it through a sharply inclined channel or pipe before it strikes the wheel. But the designer of the Agora mill seems to have hoped to combine the two principles: the gradient indicated by the floor tiles of the mill-race where they are preserved 15 m. to the south will bring the channel, restored, to the wheel-race at a height of *ca.* 1.40 m. above the wheel. This is certainly too high for the water to fall uncontrolled onto the wheel; some such solution as that suggested in Figure 1 must have been adopted to avoid loss of both water and efficiency. When the wheel was to be stopped a simple trap in the floor of the channel above the south wall of the wheel-race let the water fall directly to the floor; both common sense and modern practice are enough to suggest this, while the extraordinarily heavy lime deposit which covers this wall from top to bottom is ample proof of it. The channel, where it is carried above the ground on what Frontinus calls the *substructio*, is *ca.* 0.42 m. wide and 0.42 m. deep, floored with rectangular tiles; below ground, north of the mill, and at the south where it first appears, it is deeper and unpaved, its walls built up of rubble and mortar, covered with semi-elliptical drain tiles.[1]

Fig. 14. A Modern Wheel at Livadia in Boeotia

The axle, like the wheel, was of wood; a single beam *ca.* 3.50 m. long, *ad tornum aut circinum fabricatus.* Vitruvius says of it only *capitibus lamna ferratis.* We can be more specific: the diameter of the shaft was a little over 0.20 m.; the metal ferrules, the *lamminae*, were placed, not at the ends, but a little back from them, and the projecting wood worked down to form the bearing (Fig. 10). Modern practice and the wear on the east socket permit us to restore these details with reasonable certainty.[2]

[1] Immediately north of the wheel-race, outside the door of the mill-room, the tiles have been replaced with re-used marble slabs (Fig. 1); that this was done just before the destruction is suggested by the fact that the surface of the path which led down from the street to the doorway had not re-formed before the whole building was abandoned. A manhole lined with circular tiles, 5 m. to the north, permitted easy cleaning (Fig. 1).

[2] Fig. 15 and Fig. 16, *1, 2, 3* show the details of the socket. Note the deeply worn groove left by the 0.04 m. wide metal collar; note, too, how the sloping floor of the socket gives us at least a hint of the taper of the axle (this is exactly the way in which such wooden shafts are treated today).

The centre of the shaft, in the last phase of the mill, was 0.20 m. above the floor of the sockets. This leaves space to set into the sockets wooden blocks, *stipites*, hollowed out above to receive the ends of the shaft.[1]

On the axle, within the mill-room, the vertical gear wheel, the *tympanum dentatum ad perpendiculum conlocatum,* was fastened. Its position, almost in the centre of the pit, and its diameter, 1.11 m., are, happily, fixed: at some time during the long life of the mill the rim of the *tympanum* has struck the upper edge of the pit at the south and, little by little, has bit deeply into stone and brick, wearing them to glassy smoothness.[2]

Fig. 15. The East Socket

For the size and position of the horizontal *tympanum* there is also evidence, even if it is less precise. The solidly founded block of marble below the east bearing of the axle (Fig. 4, ε; Fig. 15) is justified only if we assume that it carried the supports for the bearing block in which the vertical shaft was set. Thus the diameter of the wheel cannot have been much more or less than 1.36 m.[3] This is considerably larger than that of the vertical *tympanum,* and means, of course, a proportionate loss in speed. But it is likely that the flow of water through the mill-race was never such that the mill-wheel developed any surplus of power; and speed, in late Roman Athens, was doubtless a matter of little importance.

How all this is to be held in place: how the millstones and the *infundibulum* are to be supported, Vitruvius did not think it necessary to specify. Nor need he have; a modern mill shows what is needed: the millstones must be set directly above the horizontal *tympanum,* whose axle, passing through a bearing in the lower stone, turns the upper. If we have little beside the

[1] These bearing blocks were presumably made of one or more pieces of wood, the grain running up and down, strapped, below the bearing, with *ferreae lamminae* to prevent splitting. The wear on the east socket can only be explained if the bearings were of wood; a metal bearing, if it wore out, would have been replaced at once.

[2] Neither this wear nor that on the east socket belongs to the last period of the mill, when the shaft was set too high. But the mill was in use for more than a century and the wooden parts must have had to be replaced on more than one occasion. It has not seemed too great a stretching of the facts to treat the evidence as though it all belonged to one period.

[3] For the construction of the *tympana* we can say with certainty only that the teeth were set as we have shown them (Fig. 10); teeth set around the circumference in the same plane as the wheel would have broken when the wheel came in contact with the side of the pit. The builders of modern Greek mills make the teeth of short sections cut from the limbs or trunk of the *πρινάρι* (the ancient *πρῖνος*), the holm-oak, unworked except for removal of the bark. The depth and sharpness of the wear suggest that the circumference of the wheel was bound with an iron strap.

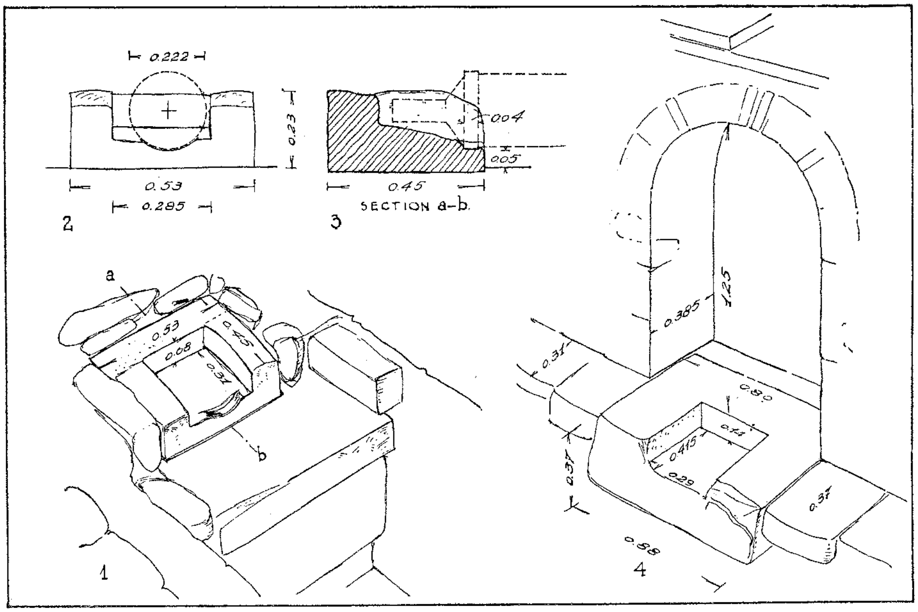

Fig. 16. Details of Sockets for Bearing Blocks

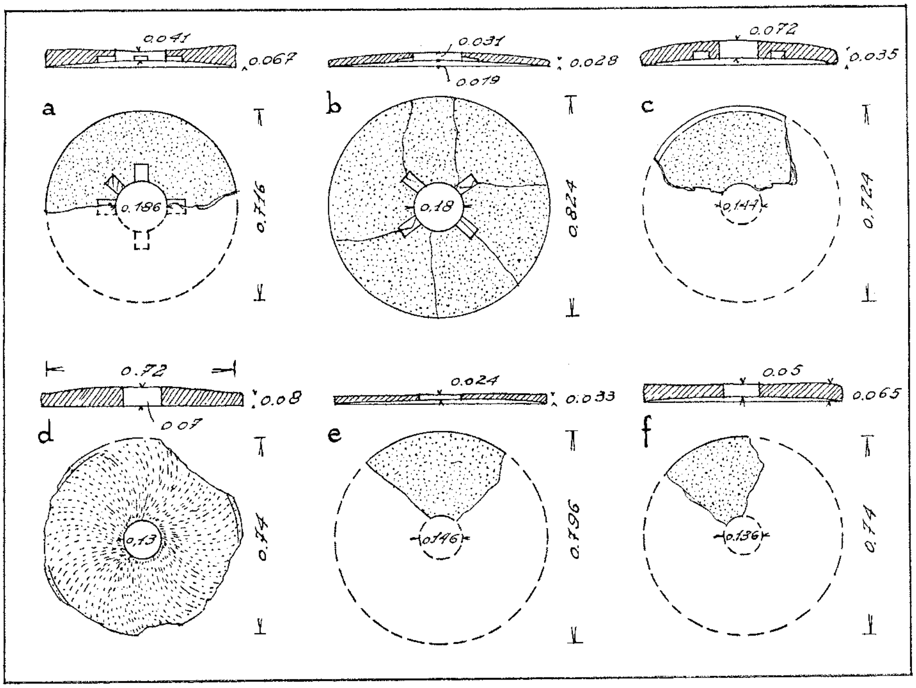

Fig. 17. The Millstones

diameters and the positions of the *tympana,* we have at least samples of the millstones and something to indicate the arrangement of the platform on which they rested.

The requirements for the platform are simple. It must be high enough to clear the gears comfortably and to permit a man to crawl underneath and into the pit to lubricate bearings or make necessary repairs. It must be high enough, too, so that a sack may be stood below it to receive the fresh-ground flour. It must be long and wide enough so that a man may work on it, lifting the heavy bags of grain, emptying them into the hopper—the *infundibulum.*

There is also some evidence, besides the modern mill, to help us. There are no beam holes in the walls, except a series just at floor-level; clearly the platform stood essentially free of the walls. That it did so is easily explained: rubble and mortar walls are ill-suited to withstand vibration, which here may have been considerable. There are no post holes in the floor; it is hard to see why, but we must do what we can without them. In suggesting a restoration of the foundation for the platform we have used the ledge at the north edge of the pit (Fig. 4, ζ), the small projection just at the south side of the opening (Fig. 4, η), together with its mate which is to be restored at the north and the curious row of heavy square tiles close to the south wall of the room (Fig. 4, θ). There are beam holes in the south wall of the room at two points (Fig. 7; cf. Fig. 10): one near the middle, just opposite the east end of the ledge where a bedding worked in a projecting stone indicates a corner (Fig. 8, in right foreground); the second close to the southwest corner. Both are at the level of the row of tiles. A third beam hole appears in the west wall of the room, opposite the last tile and *ca.* 0.11 m. above it. The breaks at either side of the opening above the pit[1] and at the west end of the ledge (Fig. 8—the wooden braces are, of course, ours) must mean that beam-ends or braces have been torn out. But the levels are a little puzzling even when the restorations demanded by the evidence are made.[2]

We must doubtless make allowance, on the part of the builders, for a willingness (not infrequently observed in their modern descendants) to substitute for careful workmanship at the start an elaborate arrangement of wedges, braces, struts and such makeshift devices. For the height of the platform, a metre or so above the floor will be ample, with a pair of steps for easy access.[3]

[1] Quite possibly a third bearing should be restored at the east side of the opening.

[2] Taking the floor of the room as zero, the levels are as follows: the ledge (its west end restored), −0.175 m.; the projecting shelf, south of the arched opening, −0.17 m.; the westernmost tile, opposite the beam hole, −0.162 m.; the fourth tile, opposite the centre of the beam hole, −0.11 m. A complicating factor is the axle whose centre is only 0.02 m. below the level of the ledge, the shelf and the western tile; but the original axle for which the installation was designed may have been as much as 0.10 m. lower.

The original purpose of the row of tiles remains obscure. If the whole floor or a part of it was originally tiled, all traces not only of the tiles, but of the thick cement-bedding in which they were laid, have disappeared.

[3] In the restored section, Fig. 10 B, we have used a broken line to indicate those parts for which we have no evidence whatever.

Now the stones (Fig. 17): two are completely preserved or nearly so; happily, one (Fig. 17, *b*) is an upper stone, one (Fig. 17, *d*) a lower; unhappily, they are not a pair. But there are fragments of four others, all of which are upper stones; the diameter and profile of one of them (Fig. 17, *a*) would make it a very good mate for the solitary lower stone. The material of all is rough, gray, volcanic stone, which is the common material for millstones in Greece throughout antiquity.[1] The lower stone is slightly convex above, flat below, with innumerable tiny channels on its upper face running in a whirling pattern from centre to edge.[2] It must be fixed to the platform or, better, to some sort of wooden bed which can be raised or lowered with wedges. Through its central hole, fitting tightly, passes the vertical shaft, terminating in a double "swallowtail" of metal by which the power is finally transmitted to the upper stone (cf. Fig. 10 B). This is concave below to fit the convexity of the lower stone but may be convex, flat or even concave (Fig. 17, *a*) on top. Four shallow notches in the under side at the edge of the central hole held the "swallowtail" in place.[3] Remarkable by contrast with modern stones is the thinness of these. No doubt they are badly worn down—to the point of uselessness, perhaps, else they would scarcely have escaped the looters who ransacked the mill at the time of the destruction. The thickest of the fragments is *ca.* 0.08 m.—only a fraction of the thickness of the stones used today—an indication surely of the relative simplicity of this establishment.[4]

Set above the millstones an *infundibulum*, a simple hopper of wood such as is often illustrated in Roman art,[5] and the mill is ready to work.

Less can be said and, on the whole, with less certainty, about the rest of the arrangements within the mill. But some evidence remains. Just north of the pit two carefully placed bits of marble (both are fragments of statue bases, Fig. 4, *ι*, *κ*), together

[1] The most favored source of this stone was, so far as we know, Nisyros (cf. Strabo, X, 5, 16: ἡ τῶν μύλων εὐπορία; *Anth. Pal.*, IX, 21; Antipatros' epigram, quoted above, p. 81, where, however, *Νισυρίων* is a restoration). The ancient quarries were still visible in the nineteenth century (Ross, *Inselreisen*, II, p. 80). The excavators of Priene suggested the peninsula of Erythrae (the ἄκρα Μέλαινα of Strabo, XIV, 1, 33) or Thera as a centre of export (Wiegand-Schrader, *Priene*, pp. 393 f.). For a collection of the source material, see Fr. Ebert, *Real-Encyc.*, s. v. *Molaris Lapis*. For the commonly held notion that Melos shipped millstones in antiquity (cf., e.g., Mackenzie, *B.S.A.*, III [1896/97], p. 72) there appears to be no basis. The millstones produced there in modern, and in mediaeval, times are of another stone, a porous quartzite (Ehrenburg, *Die Inselgruppe von Melos*, Leipzig, 1889, pp. 115 ff.). The millstones most in demand in Greece today are imported from France.

[2] One notes with surprise that the upper stone must have turned against, not with, the swirl of the channels. The intention was, clearly, to assure a finely ground flour.

[3] Lindet, *Rev. Arch.*, XXXVI (1900), p. 39, fig. 21, illustrates the kind of "swallowtail" in use in France in the XVIIIth century. Note that the differing arrangements of the notches in Fig. 17, *a*, *b*, and *c* suggest as many different shapes of "swallowtail."

[4] Dr. H. A. Thompson makes the suggestion that perhaps the upper stones were weighted by blocks laid on top, thus enabling the miller to economize considerably on millstone.

[5] Cf., e. g., a relief in the Vatican (Baudrillart, *op. cit.*, p. 1961, fig. 5106; Blümner, *op. cit.*, p. 44, fig. 6).

with a beam hole in the wall opposite the southernmost, might be the supports for a table.[1] From below its southwest corner, a length of rectangular tile-drain leads into the pit (Fig. 4, λ). Here, perhaps, the grain was washed before milling.[2] Water was at hand; the small cylindrical basin against the south wall of the room (Fig. 4, μ) tapped the trench of a small water-channel, laid through here long before.[3] At an earlier period the washing place was possibly in the northeast corner of the room, drained by the channel (Fig. 4, ν) which runs from a shallow depression in the floor to the northeast corner of the pit. The channel was out of use in the last phase of the mill; its outlet was blocked by a stone set in to brace the east bearing, its covers were broken or missing, and its channel was choked with earth. The washing place may have been moved when the block of poros, of which the stump still remains (Fig. 4, ξ), was set into the floor near the northeast corner.[4]

There is little more that can be added: the threshold block has cuttings for a door that opened inwards—a slot for the wooden framing, a pivot hole for the hinge; there seems to have been a small window in the wall above the pit, through which the miller could watch his wheel (Fig. 4, π and Fig. 5 A); a great mass of fragments of roof-tiles, heaped up against the south wall by the looters, is all that is left of the roof.

The picture which emerges is reasonably complete. Our partnership with Vitruvius has been a profitable one. Without his text the problem would have been more difficult; the restoration, in many respects, more hesitant. But we have added something: Vitruvius was not writing specifications, but explaining in the briefest possible terms the general principles of a water-mill. The actual specifications would be drawn up by the individual mill-builder, who, while basing his design on Vitruvius' account, would supply the details from his own experience and adapt them to the particular requirements of each mill which he planned. And in the Agora we have now, for the first time, such a mill, one which might, as we have seen, have been designed with Vitruvius' text in hand, which is so well preserved that in nearly all its essential parts it provides a clear idea of just

[1] We have suggested its restoration in Figure 10 A.

[2] Washing the grain is shown on a very interesting molded bowl in Athens (*Ἀρχ. Ἐφ.*, 1914, fig. 3 and pl. I; cf. Kourouniotes, *Ἀρχ. Ἐφ.*, 1917, pp. 152 f.). The round object which the miller holds is certainly a sieve; and it is a basin on a stand, not a table, over which he bends. Clearly he is using the sieve to drain the water from the wet grain, not to sift it. The bowl is probably to be dated in the late third or early second century B.C., according to Dr. Thompson, who has examined it with me. Washing the grain before it is ground is still the practice in many Greek mills.

[3] The basin is 0.75 m. deep, 0.40 m. in diameter, lined with hard waterproof cement. The overflow ran out through a channel scooped in the bedrock between the tiles and the wall, emptying into the pit in its southwest corner. The built-up rim of rubble and mortar which now covers the easternmost of the tiles is certainly an addition, put on, perhaps, when accumulated débris had raised the floor in the south half of the room level with that in the north.

[4] The post, like the built-up rim of the water basin, was not a part of the original scheme, for a piece of a much worn mill-stone is incorporated in the cement bedding. How high it may have been we have no way of knowing. It can hardly have been needed as a support for the roof but possibly supported the corner of a loft or platform for grain storage, built into the northeast corner of the room.

how the builder applied Vitruvius' general rules. If we have been unable to reproduce the original specifications *in toto,* it has been possible to restore at least a great part of them, much with authentic detail, the remainder with fair certainty.[1]

The faithfulness with which the local architect clung to the Vitruvian plan is particularly interesting because of the date of the Agora mill, which can be established with some accuracy. Where the mill now stands, in earlier times, a paved street climbed towards the Acropolis. After the disastrous invasion of the Heruli in A.D. 267, after the building of the "Valerian Wall," this part of the street was for years abandoned; its paving blocks were gradually covered with rubbish, later by the gravel and sand washed down by a winter torrent.[2] When the mill was built this process was checked and a new ground level was formed, some 0.60–0.75 m. above the old (Figs. 1 and 5 B). During the excavation, much of the filling, in and below the new level was examined; a great quantity of pottery and many coins were found. The bulk of the coins are of the late fourth and early fifth centuries A.D.; four are of the emperor Marcianus (A.D. 455-457), three of Leon I (457–474). These are the latest; with them the lamps and potsherds agree: we shall not go far astray if we date the construction of the mill some time during the long reign of Leon.

The mill was finally destroyed by fire—or sufficiently so that it was not rebuilt. The floor north of the pit in the mill-room was covered by a layer of ash and carbon, as thick in some parts as 0.25 m. More than seven hundred bronze coins were found on the hard floor below this layer, and scattered through the softer filling in the southern portion of the room.[3] In the pit, in the rubbish in the bottom, covered by the charred remains of wood and iron, some thirty more coins were discovered, with several complete lamps and vases. The coins form a particularly interesting group. Well over four hundred proved legible; nearly all are of the fifth and sixth centuries (only twelve are earlier). Most of them are the tiny bits of bronze of the class called "Vandal." Justinus I is well represented, and Justinian the Great; the latest are five of the emperor Justinus II (A.D. 565–578). We must set the destruction of the mill in his reign or not long after it.[4]

The mill was planned and built nearly five hundred years after Vitruvius wrote. It might as well have been five years or fifty, as far as the actual installation is concerned, for once the principle was discovered, this simplest application of it must have been

[1] One has but to compare the drawings of the Agora mill, especially Figure 10, with restorations based on the text of Vitruvius alone (e.g. Choisy, *Vitruve*, IV, pl. 68, fig. 2; Neuburger, *Technik des Altertums*, pp. 96 f., fig. 157) to see how much the Agora mill has contributed.

[2] The remaining paving blocks, once more exposed, are visible, just south of the mill, in Figures 6 and 7.

[3] This is hard to explain. Either the mill-room had a board floor, through the cracks of which a small coin might easily slip—no single coin being worth the effort of raising the planks; or the miller could afford to be more casual with his money than the scale of his establishment would lead one to suspect.

[4] Is it simply coincidence that this is so close in date to the great invasion of Greece by the Slavs, in A.D. 577? Dr. Gladys Davidson has been kind enough to tell me that she has recently found evidence showing that the Slavs were in Corinth, which, like Athens, had been thought to have escaped these invaders.

rapidly developed. The earliest ὑδραλέτης of which we hear, that of Mithridates, at Kabeira in Pontus[1] was doubtless not very different from ours. The mills in the aqueducts at Rome[2] which Belisarios replaced with ship mills in the Tiber in A.D. 537, were certainly much the same. And today in lands which have not yet felt the full influence of the Industrial Revolution, mills like these are still in use.

The Agora mill is thus interesting, not merely as an illustration to Vitruvius but as a link in a two-thousand year tradition, a comment on what is all too easily forgotten, the conservative, the unchanging life of the mass of the population.

Only one more aspect of the mill need here concern us. That is its immediate significance for the history and topography of the Athenian Agora. A water-mill implies both a copious and a steady stream; and it suggests an Agora of a very different character from the traditional one.

Where did the water come from to turn the wheel? The "Wasserarmut" of Athens has been axiomatic with modern commentators; if the ancient Athenians themselves thought of their water supply as inadequate, none of them has mentioned it. True, Herakleides, ὁ κριτικός, found the city ξηρὰ πᾶσα καὶ οὐκ εὔυδρος.[3] But Herakleides, like more recent critics, was a foreigner; he came, doubtless, from some well-watered Asiatic homeland and chose perhaps a scorching midsummer day for his visit. There is nothing elsewhere in literature to bear out his judgment. A mean annual rainfall in Athens of 0.393 m. (*ca.* 15.5 inches) must have kept the countless cisterns and reservoirs filled, while wells tapped water at a reasonable depth.[4] Once the sources of Pentelikon and Hymettos had been brought in by the Peisistratids, the supply seems to have been quite sufficient for the demands of the inhabitants, granting that these were, by modern (and Herakleidian) standards, relatively modest.

And now the excavations in the Agora are showing that from early times a copious source, probably a series of springs, existed in this region—and still exists, for that matter; the lively underground streams which bubble out through the central area are a constant and serious obstacle to the excavator's progress. If the springs themselves have not yet been found, they lie, certainly, somewhere on the north slope of the Areiopagos: on some point here all the lines are converging—the aqueduct of the great fountain-house, the channel that fed the mill, a whole series of mains and pipelines of various epochs. Always, the supply appears to have been plentiful: in classical times it was adequate not only for the fountain-house but apparently for several capacious pipelines which distributed the water to other parts of the city; a thousand years later,

[1] Strabo, XII, 3, 30.

[2] Procopius, *bell. Goth.*, I, 19 (pp. 96 f., Bonn). Until the discovery of the Agora mill these were the latest water-mills known from antiquity.

[3] Herakleides, I, 1 (*F.H.G.*, II, pp. 254 f.; *Geog. gr. min.*, I, pp. 97 f.).

[4] The rainfall figures are modern, cf. Judeich, *Top.*[2], p. 51. Wells in the Agora region run generally from 12–14 m. in depth.

although the fountain-house had been abandoned, there was still the Roman bath to be supplied as well as our mill.

It was the destruction of the great fountain-house which rendered the water available for other uses, the desertion, late in the third century, of the Agora of the old days, which turned it into more prosaic channels. The city, which, a century or so after the construction of the "Valerian Wall," began once more to expand in the Agora region, was little more than a small University town. The complex of baths, gymnasium and lecture-halls was not unimpressive,[1] but it represented another spirit, another economy than the Odeion and the South Stoa whose site it occupied. That, fifty years later, the mill could be built only a stone's throw away is, surely, an indication of rapid decline. Justinian's edict in A.D. 529 closed the doors of the University. Only the mill survived: Athens had become a village.

[1] See above, p. 6.

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