APRIL 24TH, 1883.

Professor W. H. FLOWER, LL.D., F.R.S., *President, in the Chair.*

The Minutes of the last meeting were read and confirmed.

The following presents were announced, and thanks voted to the respective donors:—

FOR THE LIBRARY.

From the LISBON GEOGRAPHICAL SOCIETY.—Portugal and the Congo.
From the GERMAN ANTHROPOLOGICAL SOCIETY.—Correspondenz Blatt. March and April, 1883.
From the LIBRARIAN.—Report of the Mitchell Library, Glasgow, 1882.
From the AUTHOR.—Darwin and Modern Evolution. By Raphael Meldola.
—— On Philography. By Andreas Gottschling.
—— Ethnologische Forschungen und Studien. By Dr. Fligier.
From the ASSOCIATION.—Report of the British Association, 1882.
—— Journal of the East India Association. Vol. XV, No. 1.
From the SOCIETY.—Proceedings of the Royal Geographical Society. April, 1883.
—— Mittheilungen der Anthropologischen Gesellschaft in Wien. XII, Band. Hefte 3, 4.
—— Proceedings of the Royal Society. No. 224.
—— Bulletin de la Société de Borda, Dax. No. 1, 1883.
—— Journal of the Society of Arts. Nos. 1585–1587.
From the EDITOR.—Australasian Medical Gazette. No. 17.
—— Revue Scientifique. Tom. XXXI, Nos. 14–16.
—— Revue Politique et Littéraire. Tom. XXXI, Nos. 14–16.
—— Revue d'Anthropologie. No. 2, 1883.
—— "Nature." Nos. 701–703.

The election of CHARLES ROBERTS, Esq., F.R.C.S., was announced.

The following paper was read by the author:—

On the MECHANICAL METHODS *of the* ANCIENT EGYPTIANS.

By W. M. FLINDERS PETRIE, Esq.

[WITH PLATE II.]

THOUGH so much labour has been bestowed on the literary remains of the Egyptians, and there are now so many scholars who can read an inscription with ease, yet not a single student appears to have given his attention to the mechanical evidences of ancient knowledgeand skill. Beyond cursory remarks on the wall paintings that show technical subjects—such remarks as any intelligent traveller might make—nothing has been written on the methods by which such marvellous results of skill and labour were produced. The latest writer—Brugsch, in his "History of Egypt"—says of the great diorite statue of Khafra, "Unacquainted with the hardness of steel, and the marvellous action of those instruments which in our day scarcely allow the artist to feel the trouble of rough work, that primitive race knew how to conquer the resistance of the hard stone, and to animate a lifeless mass with the spirit and expression of life. No master of modern times is capable of giving an answer to the question, how they managed to overcome the difficulties of the unyielding substance" (vol. i, p. 97, English edition). Such then is our present lack of knowledge on the subject; and it was a question of special interest to me, while living at Gizeh, surrounded by the finest examples of architecture and masonry, to obtain such information and collect such specimens as might help to answer this most interesting inquiry. Most of the illustrations of work here exhibited or described are drawn from the earliest sources, the pyramids, temples, and tombs, of the fourth dynasty, constructed some time before 2400 B.C.; and later works are only quoted as additional instances of methods already known in the earlier times.

The principal result of the examination of these remains is the discovery that the stone cutting was performed by means of graving points far harder than the material to be cut; and that as the stones operated on were quartz, or mixtures containing quartz, the graving points must have been therefore of some jewel harder than quartz; since no metal, not even the hardest tempered steel, or osmiridium, is capable of cutting quartz, apart from a mere bruising action. These cutting points are found to have been bedded in a basis of bronze, in order to hold them in the right position, and move them with the requisite force.

This essential principle—that the cutting action was not by grinding with a powder, as in a lapidary's wheel, but by graving with a fixed point, as in a planing machine—must be clearly settled before any sound ideas of the methods or materials can be arrived at; and I would therefore first of all direct your attention to those examples which give the most distinct evidence on this point.

First, we have a circular piece of granite, grooved round and round by a graving point; the grooves here are continuous, forming a spiral; and in one part a single groove may be traced around the piece for the length of five rotations, equal to 3 feet;

even at the ends of this groove there is no sensible difference in its character, as if the cutting point had begun to fail; but merely owing to irregular action of the tool, the grooves become confused and cannot be individually traced further.

Another piece is part of a drill hole in diorite. This has been part of a hole 4½ inches diameter, or 14 inches circumference; as seventeen equi-distant grooves appear to be due to successive rotations of the same cutting point, we have here a single cut 20 feet in length.

Another piece of diorite shows a series of grooves, each ploughed out to a depth of over $\frac{1}{100}$ inch at a single cut, without any irregularity or starting of the tool.

Other pieces of diorite show similarly the regular equi-distant grooves of the saw, repeated in a manner which proves that the graving point travelled for at least many yards through the material, without any appreciable alteration in its sharpness.

Collateral evidence is also given by two pieces of diorite bowls with portions of inscriptions. These hieroglyphs are evidently chased with a cut of a graving point, and are neither scraped out by repeated rubbings, nor ground out by a wheel; these specimens bear, one the name of Senofru, the earliest king of whom any remains are known, and the other the standard of Khufu, his successor, and builder of the Great Pyramid. Both are undoubtedly genuine fragments, as I picked them up from the vast number of such chips which strew the ground at Gizeh.

Now looking at these examples of work,—at the depth of the grooves graved out by a single point, and the enormous strain thrown on a cutting edge in ploughing out $\frac{1}{100}$ inch thick of quartz at a single cut,—and looking to the length of the grooves produced by a single point, which cut through at least many yards of quartz without any appreciable wear, it may be safely said (after examining specimens of modern work in such materials) that it is impossible for such results to have been produced by any means, except by jewel points far harder than quartz, set in a bed so that every point shall individually do its work in ploughing out the material. Another evidence of this is seen on the granite core; there the cutting point, which can be traced, has passed through quartz, felspar, hornblende, and mica, without the least interruption; and when we consider the strain thrown on a cutting point in suddenly passing from a soft material to a patch of far harder nature, it is evident that not only must the separate cutting points have been each fixed in rigid setting, but that the setting must have been made with great skill and care to prevent the stones from being wrenched out of it, or crushed in it, by the sudden strain.

If examples of work done by any grinding process be examined, it will be seen that there is not a trace of the definite grooves such as we see here. On modern lapidaries' work, done by a wheel fed with loose diamond powder, numerous shifts in the plane of the cut may be seen, showing the outline of the wheel; but no grooves or definite ploughings in the material, produced by individual points of diamond. Similarly on the tubular drillings done with soft iron and sand by the Chinese, or the work of many other nations who are accustomed to cut stones by means of a soft metal fed with a harder powder,—on none of these that I have ever seen is there any trace of ploughing out of the material; and, indeed, it seems physically impossible that any particle of a loose powder could become so imbedded in a soft metal by the mere accidents of rubbing that it could bear the immense strain, probably of some hundredweights, needed to plough out a groove of any considerable depth in such a hard material as quartz.

This systematic use of jewel points set in some basis may therefore be considered as proved by the existing work; and from finding that the loose sand left in a cut (and also the sides of some of the cuts) are stained green, we may conclude that the metal of the setting was bronze.

What the jewels were that the Egyptians used for these stone-cutting tools is not yet known. In some of the dust left in a saw-cut, perhaps some recognisable chips might be found. Indeed, I picked out one microscopic chip, with which I scratched a quartz crystal easily. But Professor Maskelyne has not succeeded by chemical separation in obtaining any recognisable fragments. The range of possible materials is limited to but five minerals: beryl or emerald, topaz, chrysoberyl, sapphire, and diamond. Of these I have experimented with beryl and sapphire, and the deepest scratches that I could make with either of these stones on diorite are barely perceptible, not $\frac{1}{10}$ of the depth of ancient cuts on the same piece. With greater pressure the edges of the jewels crushed and crumbled without making any deeper cut. My own conclusion, therefore, is in favour of diamond having been used, though the evidence is not distinct enough to press such an opinion. Diamond is not known as a gem in Egyptian antiquities until Græco-Roman times; but as it is colourless and unpolishable, there would be nothing to recommend it to Egyptian taste, which always chose the brightest colours. Hence it might be known as a stone for use, though not for ornament; and I understand from Mr. Boscawen, that the early Babylonian inscriptions mention the "piercing stone," a name known to be employed for the diamond in later times; so that the very early statues in diorite lately found in Babylonia, which are of the finest work (like the splendid diorite work of the earliest Egyptians) may have been very possibly graved with diamond.

Next we will consider the forms of the tools used. The simplest tool of all was the straight bronze saw, set with jewels. This must have been in some instances over 8 feet in length, since the grooves run lengthways on the side of the Great Pyramid coffer, which is 7 feet 6 inches long, and some length of stroke must also be allowed for. The thickness of the saw naturally varied with the magnitude of the work. For the heaviest work, as on large blocks of basalt, the saw was $\frac{2}{10}$ inch wide; on a piece of statuary work in syenite it seems to have been ·14 inch wide; and on a small syenite trinket it was not more than ·03 inch wide. There are several examples of sawing here in grey syenite, casts from red granite, in diorite, in basalt, and in limestone. The granite coffins of the Great and Second Pyramids both retain traces of their having been sawn into shape on the outside; and Howard Vyse reports the same of the basalt coffin of the Third Pyramid, unhappily lost at sea. The largest work of sawing that I have seen in the great basalt pavement, on the east of the Great Pyramid, 1,800 square yards in area, and containing a somewhat larger number of blocks; all these blocks appear to have been sawn, and were finely finished off on the upper surface. Probably the casing blocks of the pyramids were also sawn, as I have found many slices of sawn limestone lying about; but the blocks were all pick-dressed afterwards, so that no sawing marks remain on them. It is difficult to be certain of the age of sawn limestone, as the Arabs doubtless sawed limestone freely when cutting up the casing for Sultan Hassan's mosque; but the examples of limestone here, from their locality or condition, are certainly ancient.

Another form of saw, of which there is but one proof, is a circular saw; this must have been 6½ inches diameter, used for slicing small pieces of diorite. The marks produced by the most prominent cutting point at one side of the edge of it still remain on one face of the piece of diorite here, though the surface has been polished. It has been suggested that these marks are due to a series of jewels set on a flat rotating face, for planing down the flat bottom of a dish; but, besides the facts that no flat-bottomed dishes are known, and that the polishing lines cross the surface in all directions, it would need far greater skill to set a row of stones on a face to so exactly the same level as to make such marks, than to set them on an edge for slicing. So the simplest explanation of this piece is that a circular saw was used.

Though sawing was thus freely used for cutting the outsides of the great granite and basalt coffins, some other means were requisite for hollowing the insides of such vessels. Here the inventive genius of the fourth dynasty exactly anticipated modern devices, by adopting tubular drills, as the readiest and cleanest way of removing material with the least waste of force. These tubular drills varied much in diameter, thickness, and length. The smallest is one used in alabaster only ·24 inch diameter, and ·02 inch thick. Other examples of small cores in alabaster vary up to ·52 inch diameter; a beautiful example of a mortar, the hollowing which had been begun with a tube drill, and which had been broken and thrown away, shows a drill ·7 inch outside diameter and probably ·04 inch wide. A hole in a basalt vessel is 1·8 inch diameter. A core in limestone shows a hole 1·9 inch diameter. A tubular drill hole in a lintel of the granite temple of Khafra, at Gizeh, is 2·2 inches diameter, and the thickness of the drill ·1 inch at the end: this is a particularly brilliant illustration of the form of the drill, as the core being in a tough patch of hornblende in the syenite would not break out, and hence a stump ·8 inch long still remains in the hole. This is the S. pivot hole of the doorway leading to the chamber with niches. The fine granite core, on which continuous grooves can be traced, is 2·2 inches diameter; it was found at Gizeh, and is probably of the fourth dynasty. Pieces of alabaster cores from Gizeh are 2·5 and 2·8 inches diameter; and one of them shows the interference of the side of another drill hole cutting into it. The drill used in hollowing out the granite coffin in the Great Pyramid was 4·2 inches diameter, as we find by two places in which the drill was allowed to run too deep into the side; and as the bottoms of these holes are 7·7 and 8·4 inches below the top of the block, this probably shows the length of the drill used to be about two diameters. A piece of granite coffin here has a trace of a drill hole 6·6 inches long. A piece of greenstone waste was found with traces of three drill holes upon it, each 4·5 inches diameter; this is a very interesting piece, as it is one of the class of rude stone implements found at Gizeh; from other examples I had concluded these to be all of Ptolemaic times, and this specimen effectually prevents their being attributed to a pre-pyramid period. Two holes conjoined, in limestone, are 4·8 inches diameter, and show how closely holes were placed together for hollowing out masses; these drill holes must have just overlapped by about the thickness of the drill, so that the greatest economy of labour was attained by using as much of the previous cut as possible, without scooping out any of the core of the previous hole. A piece of diorite waste shows a hole 4·8 inches diameter, with remarkably clean cut grooves ploughed out by the outermost cutting point.

Besides all these hand specimens, there is at El Bersheh a case on a far larger scale; unfortunately many things to be examined there, in a short hour or two, left me no time to examine this carefully. The rock there required to be largely cut away to afford a platform in front of some tombs of the twelfth dynasty; and all over the platform the surface is apparently covered with the circular grooves of large tubular drills about 18 inches diameter. I cleared the rubbish out of one of the grooves, and found that it had a smooth bottom, and was ploughed out by continuous motion, and not chipped; this cutting might be supposed to result from trimming out drums of columns in the rock; but the surfaces inside as well as outside the circular grooves were rough broken, and not sawn across, and in one place I found the grooves actually intersecting, where it was not required to remove the full size of a drill hole. Hence it seems almost certain that the tubular drill principle, of which examples are here before us, from ¼ inch to nearly 5 inches in diameter, was carried on still further into sizes suitable for removing rock on a large scale,—sizes which must have needed several men to turn the capstan head of the drill. Other examples of tubular drilling I have observed on the ornamentation of the alabaster of the palace of Rameses III at Tel el Yahondiyeh, of the twentieth dynasty, in the British Museum; and on the great diorite statue of Khafra of the fourth dynasty, found at Gizeh: on the latter there is the end of a tube drill hole, 1·5 inch diameter, just between the feet, showing that the space between the legs had been roughed out by running a drill hole down there. Tube drills were also in constant use for beginning the hollowing out of the great diorite bowls, to remove the material from the axis more quickly and easily than could be done by turning on the lathe alone; the proof of this is seen in the circular groove in the inside of most of these bowls; it is here seen in a piece of black diorite bowl from Sakhara, and in a piece of white diorite bowl from Gizeh. It might be thought that this line was only an ornament, and on some examples it is clearly an added ornament, as it is graved out irregularly; but the type originated in the bottom of the drill hole not having been cut away in turning the bowl, as may be seen on the piece from Gizeh, where the groove clearly does not belong to the same centering as the turning, but falls off altogether into the regular curve on one side. These tube drill holes were also used in hollowing more upright vessels, as may be seen from the bottom of a drill hole showing in the portions of turned basalt and alabaster cups of the pyramid period from Gizeh. Probably the vases, which have a hole through the bottom for ease of turning out the hollow, afterwards plugged up, were begun in the rough with a tube drill hole right through the block.

A peculiar feature of all the cores and holes made by these tubular drills is a certain amount of tapering always to be found. This tapering cannot have been produced by the mere rubbing of the side of the drill in turning round in the hole, since, not only would such a cause be quite inadequate, but the grooves ploughed out by the cutting points are just as distinct on the sides of the hole or core where it is tapered, as at the lower part. Hence it seems that not only did the Egyptians set cutting jewels round the edge of the drill tube, as in our modern diamond crown drills, but that they also set cutting stones in the sides of the tube, both inside and out. Thus the hole was continually rimered larger by the tool, and the core turned down smaller, as the cutting proceeded; and this enabled the tool to be withdrawn the more readily from the groove, as the space is thus wider at the top than it is at the bottom.

Other drills, not tubular, were used for very small holes, such as those in the symbolic eyes here, which are drilled in syenite, 1·2 inch long, though only ·08 inch diameter.

A point that should be noticed in the use both of saws and of tubular drills is the immense pressure that must have been applied to make the cutting points bite so deeply into the stone, and cut the stuff away so rapidly. The grooves $\frac{1}{100}$ inch deep in quartz must need a pressure on the point of much over a hundredweight; since a pressure of about 10 lbs. does not cut scratches $\frac{1}{10}$ of the depth of these, to say nothing of the material removed in the breadth of the groove. If, then, each cutting point on the saw or drill had a pressure on it of a hundredweight at the very least, and there were probably at least ten points occupied in making the whole breadth of the cut of the saw, this would show that the minimum pressure of at least half a ton must have been applied; and it would seem more likely that two or three tons would be the working load on one of the 4-inch drills cutting in granite. What, also, shows this enormous pressure is the rapidity with which the tool sunk into the stone. We do not know the length of stroke of the saw, but in a drill hole, or still better on a drill core, the exact length of stroke can be seen. On the granite core here the grooves are a double spiral, showing that they were made by two stones on opposite sides of the tube; and the pitch of the thread is $\frac{1}{12}$ inch, the circumference of the core under 7 inches, and therefore the rate of sinking the cutting was $\frac{1}{80}$ of the distance travelled by the tool. If we only imagine sawing a block of wood 7 inches thick, cut with a saw making 1-foot strokes, it would be thought quick work to cut down 1 inch in seven strokes in any but the softest wood. Yet this is the Egyptian rate of cutting, or tearing through, the hardest blocks of stone known, diorite and granite. The wonder is how any bronze tube or saw-blade could bear the requisite pressure without doubling up, and how the jewels could be set in any sockets to support them against such a violent drag.

Not only was a rotating tool employed, but the further idea of rotating the work and fixing the tool was also familiar to the earliest Egyptians. The fragments of bowls turned in diorite, which are here, will show this. One piece of the bottom of a bowl shows the characteristic mark of turning; not only are there the circular grooves of the tool (showing it to have been a jewel point, as on the saws and drills), but also the mark of two different centerings: this shows that the work was knocked off its centre by the force of turning, and afterwards reset; in such a case it is impossible to hit the old centering accurately, and we have here that trouble, that every turner knows so well, of the cuts on the new centering not running smoothly into the others, but meeting at an awkward break in the surface, and so forming a cusp of the curves on the two different centres. Other specimens of turning in black granite, basalt, and alabaster, all of the pyramid period, are also here. The finest examples of turning in hard stone are in the British Museum. A small, highly polished, narrow-necked vase in diorite, or rather in transparent quartz, with veins of hornblende, has its neck only ·05 inch thick. A large vase of syenite is turned, inside and out, remarkably thin, considering the size of the component crystals. But the greatest triumph is a bowl of diorite (No. 4716), translucent and full of minute flaws, which must render it very brittle; yet this bowl, 6 inches diameter, is only $\frac{1}{40}$ inch (·024) thick over its greatest part; just around the edge it is thicker, in order to strengthen it, but a small chip broken out of the body of it shows its extraordinary thinness, no stouter than thin card. An alabaster vase, of Unas of the fifth dynasty, almost rivals this in thinness, being only $\frac{1}{20}$ to $\frac{1}{30}$ inch thick; but the softness of the material makes it of far less interest. A very favourite plan for narrow-necked vessels was to turn them in two or three parts, and join them together, sometimes finishing off the inside on a fresh centering on the lathe. For this finishing, and also for hollowing out vessels in one piece, a hook tool must have been used. The brown limestone vase here is an example of this. This vase, and also the alabaster vase here, are probably of Greek date: the alabaster is of a minimum thickness of ·07 inch in the neck and ·12 inch in the body. Both these vases illustrate the curious idea of employing turning to hollow out a uniform inside, while the outside was finished by hand. The reason of this where a handle had to be left in cutting is obvious, but this system seems strange in vases with uniform circular outsides. The familiarity of the Egyptians with turning in later times is shown on the abundant copper coinage of the Ptolemies; every blank has been turned after its casting, to leave a clean face for striking; the two centre punch marks may be seen on every coin, and on many specimens (such as those here) the marks of the turning are also visible.

For the use of a hook tool in turning the insides of vases, a very rigid rest, or even a mechanical tool-holder, is almost necessary; but one specimen here shows that the early Egyptians were already familiar, not only with lathes and jewelled turning tools, but with mechanical tool rests, and sweeping regular arcs in cutting. The diorite bowl, of which this piece is a fragment, has been turned as a segment of a sphere inside, by a tool working from a fixed centre in the axis of the lathe, with a radius of 3·94 inches. Having cut this spherical curve, the centre of play of the tool was shifted about ·5 inch higher, and ·7 inch out of the lathe axis; and a fresh arc was struck from this centre on the bowl, thereby cutting out a fresh curve which left a raised lip around the edge. The proofs of this explanation of the process are found in the exact equality of the two curves—that of the bowl in general, and that under the lip—in the fact of the principal surface exactly falling in with the inner edge of the lip, in the fact of the true circularity of the section of these curves, and in the cusp formed where they meet, an awkwardness which no hand-turner could ever take the trouble to make, but which necessarily results from a sudden change in the centre of the arc of the tool. All these details have been worked out from very careful measurements of this piece, using successive templates of slightly varying curves, to measure the exact curvature, &c.

For the intricate work of the statuary, the straight lines and uniform curves of saws and drills are only available in roughing out the work. The statue in diorite of King Khafra shows us some further details; where the legs join the front of the throne there is a groove running along the irregular curve of the calf of the leg—a groove which has been cut too deep into the throne, and left as a mistake. This shows that a hand-graving toolwas used to score out the varying curves of the limbs in the block, and so to detach a layer or coat of stone from off the intended form of the figure. This is a process worthy of the men who hollowed out their granite coffins, by rows of tube drill holes; like a modern carpenter's hollowing a block of wood, by centre-bit holes. The effect of this same graving tool, worked by hand, is seen between the fingers and toes of the figure; the grooves it cut are ·15 inch wide, and are often run too deeply into the stone, thus revealing the method. Much of the work was hammer-dressed and then polished down; the hieroglyphs are apparently all done by picking, though in small hieroglyphs, as we have seen, a graving point was used to cut the lines.

Before leaving the question of the forms of tools, we may note that in the tombs of the fourth and fifth dynasties carpenters are represented using saws (always curved along the cutting edge), mallets, and chisels, two forms of adzes, and the bow-drill. Their hands always grasp tools with a clench of the whole hand, and not between thumb and finger, although the scribes always hold a pen as we do.

Besides sawing, hammer-dressing was largely used; and in some cases (as in the King's Chamber and Antechamber of the Great Pyramid) the saw was used to mark out the work; grooves were cut about half an inch deep around a block, and then the hammer-dresser was left to trim it down to the plane of the grooves. Also on sawn blocks, the surfaces to be placed in contact were usually hammer-dressed, to leave sufficient space to hold the cement, while just around the edges of the surfaces they were left quite smooth. Hence the stones would be in contact, and the joint quite microscopical on the outside, while there was a fair thickness of cement on extremely roughened surfaces inside the joint. This may be seen here on two specimens of basalt, and one of diorite.

For dressing surfaces truly flat, the regular custom of the workmen was to use a trial plate, or facing plate, prepared as a true plane, and smeared with red ochre. Wherever the ochre came off on the stone, they knew that there was an excess, and accordingly picked it away. The tool used appears to have been a sort of small adze, with which the stone was sliced down, very delicately and regularly, by hand. All the blocks of the Great Pyramid casing were prepared with these facing plates, as may be seen by the remaining touches of ochre on all the prominent points. Not only on building stones, but on rock dressing the same ochreing is visible; on the floor of the south-west socket of the great pyramid, and also on the sides of rock tombs. Where the stone was much larger than the facing plate, as was the block of granite over the King's Chamber doorway, about 8 feet × 12 feet in area, there a diagonal draft was cut along the stone, from corner to corner, and thus any wind in the plane of the face was avoided.

In the existing casing stones, the average thickness of the joints, 6 feet in length and 35 square feet in area, is only $\frac{1}{50}$ inch; and this shows that the straightness and squareness of the surfaces must be true to $\frac{1}{100}$ inch on an average. The levelling of the stones is equally fine, the average variation being only $\frac{1}{50}$ inch over about 100 square feet area, and only differing $\frac{1}{50}$ inch at a distance of 40 feet. Such results could not be obtained by plumb-line and square, and it is only by water-levelling on still days that such accuracy could be realised. In a painting at Thebes, the workmen are apparently shown chiselling down a plane face to a stone; they have a string stretched quite clear of the stone, over two offset blocks, one at each side, and on their applying an offset piece to the face of the stone they see whether the face is in excess; this is a beautiful method of work, as the excess does not bulge out the string, but can be exactly measured as they proceed, and also the string is not removed while working, as the chisel can be used beneath it, and so each stroke can be quickly tested as they proceed. The face on which they work is placed vertical, so that no bellying of the string will cause inaccuracy. The string is applied both diagonally and parallel to the sides, so as to observe any winding in the plane.

In the use of plaster the Egyptians were very free. This is shown in the flaws in the pillars of the granite temple, in the roof of the King's Chamber, and the Antechamber in the Great Pyramid, and in the granite passage of the Second Pyramid; all these are filled with plaster, which is tinted red, so that it should not show. The plaster is often, perhaps generally, laid on with the fingers; the grain of the skin even can be seen on plastering in the angle of the King's Chamber roof; but the flat surfaces were smoothed by a flat tool. The great freedom in the use of plaster probably arose from the necessity of using it to fill the flaws in the rock-cut tombs: a large flaw was usually cut smooth, and filled in with blocks of stone inserted; but smaller flaws were filled with plaster, often of far greater durability than the stone itself, some of the hieroglyphs on plaster in the tombs at Giseh being as sharp as when first moulded.

For marking out their work the Egyptians generally used red ochre paint; just such as is daubed on all the boxes sent by railway at this day, in lieu of paper labels. In cutting a passage in the rock, a rough driftway was first run: the roof of it was trimmed, an axial line in red was marked on the roof, and the sides trimmed to gauge from the axial line. On the sides of the forty-three granite beams (averaging 50 tons weight each), which roof the King's Chamber, and the spaces above that, the workmen's lines may be seen marked in red about $\frac{1}{2}$ inch wide; these are usually—(1) a line at some definite distance from the dressed face, from which the dressing was gauged; (2) a mid-line at half the length of the beam; (3) a line near each end showing where it should be placed on the supporting walls; (4) a line 1 cubit from each end, by which the lines of support could be measured off in case they were defaced; and (5) smaller lines in black, about $\frac{1}{10}$ inch wide, marked on the red in some parts, to give more definite points of reference. Thus we see that, besides marking out the work in the usual modern way, the workmen were careful to supply lines which were not to be cut away or hidden in course of work; from which offsets could be taken, so as to see that they had not overshot the mark in their cutting or placing of the stones. In lining a rock-tomb with fine stone, each course was not gauged to uniform thickness before it was built in; but after laying it, a red line, at the level of the top of the lowest stone, was run around the chamber, to mark where the dressing down was to take place.

In laying the rough stones of the mass of the masonry of the pyramids one on the other, a very curious system was adopted of sinking the irregularities of the stones of each course into those of the course below them; thus each course bears on it a sort of plan, sunk on it to different levels, showing all the stones that come above it. This was also the arrangement in fitting masonry on a rock-bed, as in laying the causeway of the granite temple, and in fitting fine lining of granite, limestone, &c., against a wall of megalithic blocks.

For such a system to be carried out in pyramid building, it became requisite to plan all the courses on the ground before they were carried up and built into place; and this was certainly the method, as on all the blocks of casing stone may be seen lines showing where the edge of the stone above it was to come; the meaning of these lines may be seen on the blocks of core masonry, where they will be found always to mark the edge of the superincumbent stone. The same planning of the work also took place for all the internal chambers, as on the roofing blocks of the highest space over the King's Chamber may be seen many of the numbers of the blocks in consecutive order. The casing of the pyramid was cut to angle before it was built in, as there is a difference of 4′, or ·09 inch on their length, in two adjacent blocks. In the Third Pyramid the granite casing has been left in the rough on the face, to be dressed down afterwards; so the rule on this point does not appear constant.

The method of fine dressing all the limestone was not by grinding, but by very careful picking, as if with a small adze; this enabled the flatness of the work to be tested by the trial-planes as it went on; and the usual standard of flatness appears to have been that no space more than a couple of inches across should miss touching the true plane, within the thickness of the smear of ochre; usually the ochreing is found on points not over an inch apart. The surfaces of the chambers of the pyramids, which are built of limestone, were probably finished off after building, as on the walls of the gallery pickmarks of the dressing may be seen across a joint. In the granite temple the stones were apparently built with a rough excess left on the face, like that on the granite casing of the Third Pyramid, only 1 or 2 inches thick in place of 6 or 8 inches. This excess was afterwards dressed away in finishing the face, as then was produced the curious appearance of each stone running a little way round the corner of the chamber, or the corner being cut out in the solid stone.

On the methods of quarrying I can only speak of limestone, as I had not the advantage of seeing the sandstone or granite quarries. At the great quarries of Turra and Masara, on the opposite side of the Nile to the pyramids, there was a regular system of work. A square gallery was run into a good stratum of rock, the gallery being about 20 feet square. Similar galleries were run parallel with each other, leaving an equal space of rock between them; then cross galleries were cut, and so the whole space was reduced to an enormous hall, 300 or 400 feet wide, the roof of which was supported by rows of pillars about 20 feet apart, and each 20 feet square. Disused parts of the hall were filled up with the waste chips. Such halls do not necessarily show on the outside of the cliff, as they may have but a single opening, and be almost entirely in darkness inside. To excavate these regular galleries, the workman—cutting a row of foot-holes, by which to ascend to the top of the gallery—there excavated a recess the width of the gallery, the depth back of the one block of stone to be removed, and high enough for him to lie upon. Then cutting a groove downward behind the intended block, while others cut grooves horizontally inwards from the face, and vertically along the gallery sides, the block was at length liberated from the rock, and ready to be removed on an ox sledge down the causeways, which descended to the plain below. For merely hollowing away rock which was not required for use, grooves were cut wide enough to stand in, and then cross grooves, by which at length the blocks could be broken out. This is seen in the subterranean chamber of the Great Pyramid, and the cutting around the Second Pyramid. In the open-air quarries at Nezlet esh Shekh Hassan, the system was rather different. There the fissures in the limestone were untouched, as the sides of them were inferior stone; and the quarrymen actually left all the fissures, as it were, enclosed in a wall of rock, standing like a honeycomb all over the hill. It is possible to walk a long way on the tops of the fissure-walls, looking down into the workings 20 or 30 feet below. They even cut foot-holes to descend into a space where good stone could be obtained, and must have hauled up the blocks out of the pit they excavated, until the approach of other pits, and workings between the fissures, enabled them to cut a gap about 6 feet wide, straight down the fissure-wall, and so get easy access to the bottom of the place which they had sunk to such a depth.

Granite was, in the pyramid times, often obtained from boulders taken from the bed of the Nile: all the casing of the Third Pyramid, and some stones in the Great Pyramid, showing this. But other and larger pieces, such as the beams over the King's Chamber, and over the granite chamber in the Third Pyramid, were quarried; and in order to determine the plane of fracture, not only was a groove cut along the surface, but holes were roughly drilled at every couple of feet right through the mass; the halves of these holes on the tops of the blocks may still be seen.

For moving the stones readily, without bruising their edges, lugs were left projecting from the surface, which was otherwise dressed flat; these lugs were knocked off after the stone was in its place, and the remainder of the surface was polished down. They may be found remaining on the walls of the spaces over the King's Chamber, and their traces may be found on the walls of the chamber itself. A cast of one shallow lug, from the granite leaf in the Antechamber, is before you; and I picked up a large broken-off lug on the hill of Gizeh. Another plan, when the block was not yet faced down, as on the granite casing of the Third Pyramid, was to cut hollows in the rough excess of the stone, to get the ends of levers under it; hollows were also cut in the lower edges of rough backing stones, as in those of the Mastaba el Firaun of King Unas at Sakkara.

The method of raising such immense blocks is not known, except by inference. Considering that undoubtedly the easiest way would be by rocking the block, and so alternately raising two piles near the middle of it, and that Herodotus says that machines composed of short pieces of wood were used, there is little reason to doubt this explanation given by Howard Vyse. But something beyond brute force was employed, as, for instance, in placing the lower granite portcullis of the Second Pyramid; there a block, which would need forty or sixty men to lift it, was slid on its edge along a passage only 3½ feet wide; and then slewed round in a complex way, so as to turn it up into the grooves prepared in the rock for it to slide in. Not more than four men could well work at it, and they in a cramped space; and hence some great advantage of leverage, skilfully applied, must have been available.

Finally we will briefly notice the system of organisation that appears to have been required in the enormous works of the Egyptians. The prodigality of labour shown in their buildings has often drawn reproaches on their inhumanity and folly, from modern writers who have never lived in the country. But to any one who sees that during a quarter or a third of the year all agricultural labour is absolutely at an end, by reason of the inundation, and that the modern people merely idle away their time in enforced business, it may rather seem that to organise and train a small proportion of the effective labourers of the country in regular work during that time was really a great benefit to the national character. To require a man every six years to serve on the public works, during the season when he could do nothing else, would certainly not be a great hardship, and such a system of levying would suffice to build the Great Pyramid entirely in the twenty years which Herodotus states, without anything beyond easy, steady labour. When we consider that all the transportation of stone for the great buildings which cover Egypt must have been done during the season of High Nile, when water-carriage was to be had directly from the quarries to the site on the margin of the desert, the special utility of labour on such works during the inundation is plain. And we have an historical notice of this system by Herodotus who states that the levies for the building of the Great Pyramid only worked for three months at a time. Thus it was by the natural and obvious system of employing a fraction of the population, during the season when all ordinary labour was at a standstill, that the Egyptians were so readily able to command such an immense amount of force as was requisite to carry out their great conceptions.

POSTSCRIPT.

In consequence of the remarks made on the granite core, I have examined it more carefully. It offers apparently a complete proof that the lines were cut by fixed points, and not by the rubbing of a loose powder; for the grooves are cut as deeply in the quartz as in the felspar. And the felspar being somewhat rubbed down, by general friction, the lines are actually cut through a greater thickness in the harder quartz, which stands above the felspar. Now no loose powder could cut down exactly to the same depth in materials different in hardness, like quartz and felspar; still less would it cut more out of the slightly more prominent quartz; but a fixed point must cut to the same depth in each material.

The spiral was described as a "drunk screw"; I therefore traced very carefully a normal plane, at right angles to its axis, and measured off the distances to the spiral: they are thus, at successive quarter turns, in inches:—

	Quarter turns.				First repeated.
Turn 1 ..	3·14	3·11	3·07	3·08	3·06
„ 2 ..	3·06	3·03	2·99	2·97	2·95
„ 3 ..	2·95	2·94	2·91	2·87	2·83
„ 4 ..	2·83	2·82	2·80	2·77	2·76
Mean	2·995	2·975	2·942	2·922	2·900

Here, if there were any "drink" in the screw, it would appear as an irregularity in the order of the means of such quarter; whereas they proceed as regularly as the small variations due to texture, will permit. There is not $\frac{1}{100}$ inch irregularity in the mean spiral, though the pitch is $\frac{1}{10}$ inch.

The spiral could not be produced by the mere withdrawal of the tool, as it is too deeply cut to have been made without great force; and it is wholly unlikely that a tool should be withdrawn with such regularity. Again, as there would be from $\frac{1}{10}$ to $\frac{2}{10}$ inch of loose dust between the tool and the tapered end of the core, the cutting points of the crown would not reach it in withdrawal; and if they did so accidentally they would not touch the core in a continuous line all round, but only on one side.

That there are lines on modern drill cores is not to the point. Those cores are not tapered, and hence the lines can there be produced by the crown.

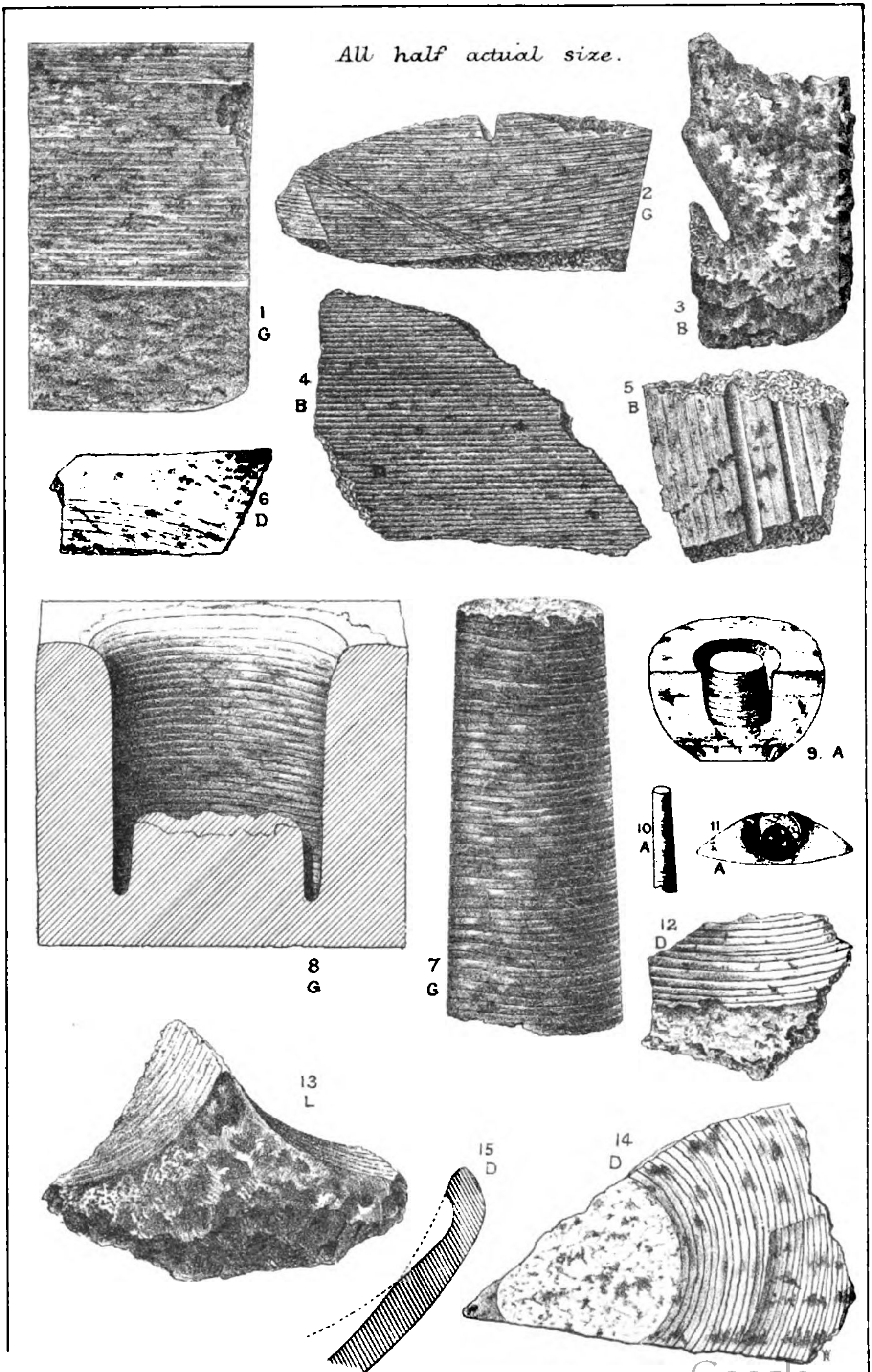
On examination it seems most probable to me that the coning was not due to stones set with different projections from the drill side, but rather by a row of stones up the side projecting uniformly. Then when the top weight was tilted over to one side, or did not balance truly on the drill head, it would drag the drill over, and thus make it enlarge the hole and taper the core, as it cut downwards.

An engineer present has remarked to me that the manufacture of hammers good enough to dress down granite on such a very large scale, as in the Great and Third Pyramids, implies almost as much skill as any other method of dressing the stones.

The result, then, of a much closer examination of the specimens, is to confirm the conclusions as to the method and quickness of working stated in this paper.

The diorite statues of Goudea (before 1500 B.C.), lately brought from Chaldea to the Louvre by M. de Sarzec, show traces of being

EARLY EGYPTIAN STONE CUTTING



A. *Alabaster*. B. *Basalt*. D. *Diorite*. G. *Granite*. L. *Limestone*.

wrought by similar tools to those here described. Between the feet of the largest statue are the bottoms of four tube drill holes 1½ inch diameter; the groove is $\frac{1}{20}$ inch wide, and the core still projects about ·08 in one hole. On another statue are five tube drill holes, ·8 inch diameter, with grooves $\frac{1}{30}$ inch wide. There are no traces of lines on the sides of the holes, so they might have been done by a loose powder; but on a diorite fragment in one of the cases are very regular equidistant lines, which, though but slight, are yet far too uniform and sharply cut not to have been made by fixed points regularly advancing, as in tubular and drill work. There is also a piece of a well-turned bowl in lime-stone. Hand-graving tools were largely employed on the figures; the long inscriptions, the fringe of the garments, the divisions on the architect's plotting scales, and the cutting between the fingers and toes, were all done in the diorite by a cutting or scraping tool, and not by hammer and chisel. There is no trace of sawing at present visible on the statues.

The granite shrine of Ahmes (twenty-sixth dynasty), also in the Louvre, shows in the pivot-holes that tube-drilling was used as late as that period by the Egyptians.

Description of Plate II.[1]

Fig. 1. Sawing in granite, end of Great Pyramid coffer. Saw run too deep, twice over.

„ 2. Sawing in granite, with saw-cut across the block. Found at Memphis.

„ 3. Sawing in basalt; part of basalt pavement of ¼ acre area at Gizeh, thus sawn.

„ 4. Sawing in basalt; same locality, showing lines of cutting well.

„ 5. Sawing in basalt; same locality, showing breadth of saw, cut into a slice sawn on both sides.

„ 6. Circular sawing in diorite. Found at Gizeh.

„ 7. Core of a tube drill hole in granite, showing deep cut spiral lines. Found at Gizeh.

„ 8. Section of tube drill hole in granite, showing core still in hole. Cast from Gizeh.

„ 9. Tube drill hole for hollowing alabaster mortar; broken in the making. Found at Kom Ahmar.

„ 10. Core of a tube drill hole in alabaster. The smallest known. Found at Memphis.

„ 11. Tube drill holes in an eye in marble. Showing thickness of tube. From Thebes.

[1] This Plate has been generously presented by the author.

Fig. 12. Tube drill hole in diorite, showing deep grooves of cutting. Found at Gizeh.
„ 13. Tube drill holes meeting in limestone, showing how nearly they were placed together. Found at Gizeh.
„ 14. Turning with two centerings, on a piece of diorite bowl. Found at Gizeh.
„ 15. Turning out of a diorite bowl, with fixed arcs of cutting. Found at Gizeh.

All the specimens from Gizeh are of the fourth or fifth dynasty; the others are of unknown dates.

Discussion.

Mr. John Evans complimented the author on the powers of observation he had shown in finding traces of the technical methods in use in ancient Egypt. Though inclined to accept the majority of his conclusions he differed from the author's views as to the method of drilling, by which such cores and cavities as those exhibited had been produced. Even had some extremely hard stone, such as the diamond, been inlaid in the ends of boring tubes, it would have been impossible to secure them inside tubes of a quarter of an inch in diameter. The conical shape, both of the holes and cores, implied a considerable waste of power, and this waste would only have been increased had the outside of the boring tubes been purposely studded with jewels. In saws and in boring tools of the present day, the cutting edge was intentionally made wider than the blade or stem, so as to diminish friction, and had the Egyptians adopted a crown of diamonds to their drills like those in use by the Diamond Boring Company of the present day, they would doubtless have adopted a similar precaution. Even with any amount of power and pressure, it would be impossible to bore so rapidly into hard diorite that the drill should advance at the rate of about one-twentieth of an inch at each revolution, as had been inferred by Mr. Flinders Petrie from the spiral grooves on the cores and on the sides of the circular holes. These grooves, however, were, in Mr. Evans's opinion, significant of the drilling tool having been a tube of some soft material—possibly soft copper or iron, or, as appeared to have been the case with the Swiss Lake dwellers, even of horn, which had been employed with some hard, gritty substance, such as corundum and water, and had thus ground down the circular channels. In grinding in this manner, there was a tendency for particles to follow each other along regular grooves, so that the sawn surface, as, for instance, of New Zealand jade, exhibited parallel striæ, which, however, afforded no indication of the rapidity with which the saw advanced in the stone. It was not improbable that the spiral grooves on the cores were made either in introducing the tube charged with fresh grinding material into the recess or in withdrawing it when clogged. With regard to the diorite bowls, Mr. Evans mentioned the modern jade vessels made in China, which he believed were produced by the ordinary grinding process. He had himself made some experiments in boring with wood and bone instruments in stone, using sand as the abrading material, and he had found approximately parallel or partially spiral grooves produced on the inner surface of the hole, which bore no relation to the progress made in drilling. On the whole he thought that the method of drilling stone practised in Egypt must have had much analogy with that in use in early times in Switzerland and Northern Europe, and that corundum, rather than diamonds or any other jewels, was the actual abrading agent.

Mr. F. G. H. Price had listened with great interest to the valuable paper of Mr. Flinders Petrie, and had really very little to add; but he would be glad to be informed by Mr. Petrie whether he could say what had become of the many thousand implements used by the ancient Egyptians for stone-cutting purposes, as he was unaware of the existence of any in public collections.

Mr. E. P. Loftus Brock considered that the cuttings through the hard materials shown by Mr. Petrie indicated that the boring instruments must have had cutting edges harder than the materials cut through. The lines of cutting were exceedingly fine and true, and were not blurred or smoothed, as would have been the case had any, or much, sand been used to help the cutting. The presence of so many specimens on the table, or referred to by the lecturer, appeared to indicate a more rapid system of work than anything done by prehistoric tribes. Indeed, it would have been impossible by any of their processes to cut out the huge sarcophagi, or to have formed the platforms, &c., referred to. The discoveries made by Mr. Petrie appeared to open out a new page of Egyptian history, all the more remarkable since the discoveries referred to a remote period, when recorded history itself was beginning.

Mr. A. L. Lewis suggested that the question, how and where the quantity of cutting material necessary for executing the immense amount of work done by the Egyptians was obtained, was worthy of consideration. He thought Mr. Petrie's suggestion, that the Egyptians performed their great architectural feats at times when they could do nothing else, was a very happy one.

Mr. Rudler, while expressing his general admiration for Mr. Petrie's work, ventured to suggest that, on the assumption that the ancient Egyptians used diamond-mounted drill-heads, it would be difficult to conjecture whence the necessary supply of material could have been derived. This difficulty was increased by the fact that the ordinary crystalline form of diamond was found to be useless for drilling purposes, the only kind applicable to such work being the black *carbonado*—a mineral of exceedingly local occurrence in Brazil. He consequently thought it desirable to seek for some common material in a more accessible locality. The use of emerald seemed at first a feasible suggestion, inasmuch as this stone was largely worked by the ancient Egyptians. But the speaker doubted—notwithstanding Pliny's reference to the remarkable hardness of the Egyptian *smaragdus*—whether so brittle a substance would be of much service in jewel-mounted drills. He therefore inclined rather to Dr. Evans's suggestion that corundum, in some form or other, was the agent most likely to have been used. Supplies of this material might readily have been procured from Ethiopia or from Armenia. The Armenian whetstones of Theophrastus were probably made of emery; Pliny speaks of the superiority of the Armenian *naxium*, and at one time it was imported into Greece, notwithstanding the proximity of the Naxos deposits. Probably the Armenian variety possessed superior hardness, toughness, and purity. It is doubtful whether the ancients made much use of diamond for working stone, and the Rev. C. W. King—our great authority on ancient gems—believes that the *adamas* of the early Greeks was corundum—the "adamantine spar" of some mineralogists even at the present day—rather than the true diamond. It had been suggested by Sir G. Wilkinson that the Egyptians in working hard stone used bronze tools supplied with emery powder. Without assuming that the ancients hardened copper in the way suggested by Mr. Duffield (Appendix to Dr. Schliemann's *Ilios*), it might be supposed that a comparatively soft metal, armed with particles of a hard mineral, would form a highly efficient agent. Dr. Evans had brought forward some striking illustrations of the work that may be accomplished when the matrix consists of such tissues as those of horn and wood. Mr. A. R. Wallace had described how the Uaupes in South America were able to drill holes in so hard a material as rock crystal, by the rotation of a pointed leaf-shoot of the wild plantain, worked with sand and water. The process had also been described by other travellers, who explained how the leaf-shoot of the *Urania Amazonica* was patiently rotated between the hands while the piece of stone was secured between the great toe and the second toe. These illustrations sufficiently proved that particles of an abrading material, embedded in a soft matrix, could drill into a substance quite as hard as itself, for the rock crystal was certainly as hard as the sand which attacked it. The subject of working hard stone by primitive peoples had recently been discussed with much ability by Dr. A. B. Meyer, of Dresden, in his valuable work on Jade.

Mr. Hyde Clarke suggested that the *naxium* of Armenia presupposed the emery mines of the island of Naxos, a chief source of supply to this day, and which were accessible to the Egyptians in early epochs when there was extensive navigation on the Mediterranean.

Professor Flower, Professor Boyd Dawkins, the Rev. Greville Chester, Mr. Park Harrison, and Mr. F. C. J. Spurrell also joined in the discussion.

Mr. Petrie, in reply, said that he had not intended to mention Sir Gardner Wilkinson, though he had his work in view; but as that had been alluded to, it should be noticed that he gave no explanation whatever of the methods of stone cutting; he described some of the most evident results, without any technical criticism or research; and from his allusions to the choice of soft metal for *chisels*, to be used with emery *powder*, it is difficult to see what definite ideas he had of the capabilities or use of tools. Hard powder used with a chisel would be merely crushed up, without doing any work. Of his most valuable drawing of dressing the stone by means of a line and offset pieces, explained in this paper, he does not give even one word of description. Hence, saying here that his remarks on these subjects are only such as any intelligent traveller might make, is certainly not an over-strong statement. That setting the stones inside very small tube drills would be impossible, may be freely allowed; but no tapered cores under 2 inches diameter are known in hard stones; the small cores are all in alabaster, which could be readily drilled merely by sand. The setting of stones in the insides of the tubes would not be very difficult, either through larger holes in the opposite side, or else by cutting holes right through the metal. The great pressures alluded to were only for cutting in block; doubtless the delicate bowls were thinned off by grinding and polishing; and probably they would be filled solid with pitch during the final finishing. The disappearance of the tools is not to be wondered at. The specimens of work yet found are but a small fraction of what a single tool would cut out; and of the far commoner tools, as chisels, hammers, &c., there are but very few specimens known. The jewelled tools would be royal property, and would never be buried with the workman; and the bronze would be melted up, and jewels reset, again and again, as they wore out.

The following Paper was read by the author:—

On some PALÆOLITHIC KNAPPING TOOLS *and* MODES *of* USING THEM. By F. C. J. SPURRELL, Esq., F.G.S.

(WITH PLATE III.)

ALTHOUGH in many situations where implements of flint have been found in river-deposits, flakes or wasters and minor implements have been found also, yet there has been little success in getting the waste flakes and imperfect implements, together with the tools or knapping stones with which the much-desired hâche was formed.

It is obvious that where these remains are found in coarse gravel, there will be small chance of obtaining such particulars; and if so found there would be no proof that any particular knapper produced any particular flake, or was employed for any particular purpose. But on sandbanks, in out-of-the-way parts of a river-bed, and in retired situations, such remains have been found; in fact, they are common and easy to find, and their relative age and positions at once suggest a close connection between them.[1]

Of the mode of producing flakes it is obvious that much may be inferred from the mere inspection of a flake; but when we consider the uniformity of the material we are surprised at the variety in the shape of implements and the difference in the style and method of chipping as practised by the old men.

When three years ago I found at Crayford a locality on the beach of a river, covered with a layer of chipped flints, I was able to show that the chipping had been done on the spot, and that no movement whatever of the remains had taken place since they were dropped by man.

All the stones had been obtained from the base of the chalk cliff, and it thus happened that the irregular staining of their surfaces by the iron from the gravel, helped materially in replacing the chips in their original form. The relics consisted of large and small flint flakes and minute chips, together with cores and spoilt hâches. With them I found hammers.

From the appearance of the flakes it was at once seen that several methods of workmanship had been practised, and this was more clearly brought out on their restoration into the original blocks.

In some cases the whole stone was split up into long, parallel, regular flakes (such an one I gave to Sir John Lubbock). In other stones the object was clearly to break the stone, but apparently without ulterior purpose as to the pieces detached, so coarse and clumsy were the results.

Other stones were broken evidently to obtain knife-like plates (which were afterwards carefully elaborated), and this was accomplished by means of a continual rectification of the superior (and necessary) plane of percussion from which the large flakes were struck.

In order to obtain a better stroke a continual lowering of that plane was practised by the freeing of minor flakes from it, parallel with its surface; each act of flaking, both horizontally and vertically, being frequently alternate. The restoration of flakes presents, consequently, a stair-like arrangement under this treatment.

[1] In searching the refuse of bone-caves, where flakes, knappers, and tools for working bone, &c., certainly lay with the general rubbish, it would seem that little care has hitherto been taken to collect and re-arrange them; it can only have been haste or carelessness, on the excavators' part, that lost so good an opportunity of obtaining those details which help to trace the turns of thought and ingenuity in overcoming those difficulties which enable us to distinguish the minor points marking the progress of man's mind. Though so much has been lost much may still be done, and it is to be hoped that in future greater care will be taken.

The hammers with which flaking was done were apparently ordinary flints. Such flints are much bruised at the *ends*, or the *edges* of the *end* of a long stone, broken across; and I think that this must have been their most common form, as it certainly produced the simplest kind of palæolithic chipping.

There can be little doubt that some large flints, which show a peculiar jarred appearance chiefly on flat or hollow parts, were anvils on which to rest the block.

Another method of working was to break off large or small pieces from the outside or crust of a nodule, with the ultimate purpose of getting at its interior. The flakes yielded by this method, from Crayford, as restored by me, show great irregularity of form and order of removal; they are usually broad and inelegant.

With these flakes were found two stones, which from their appearance I at once concluded to be hammers of a special shape. One of them is a green-coated flint of great toughness; it was chosen to suit the grasp of the hand, and was trimmed at either end to a suitable length. The thick layer of tough white crust on one side of it was peculiarly suitable, as resisting its own too rapid wear. It was not until this crust was worn down to the black flint that the hammer was thrown aside.

Another small chalk flint was evidently tried, but being of the ordinary kind was speedily thrown aside as unsuitable or worn out.

It became necessary to discover how this hammer was used, which I am able now to say I have done. By making experiments on this form of hammer (fig. 1, Plate III), and procuring a similar piece of stone, I succeeded in producing similar work. There was no anvil needed in this work.

The block of stone to be operated on being held in the left hand was struck by a long swinging sweep of the right hand holding the hammer, in the way a violin bow is held (in the direction of the arrow in fig. 2, Plate III). It is evident that in general the lower surface of a long hammer passing lengthways over the edge of the block would merely strike the thin edge, at (*a*), and that unless an irregularity in the hammer happened to hit further back, a flake, properly speaking, would not be detached. In order, therefore, that the hammer should strike the right spot (*b*) at once, the projecting edge (*a*) was chipped or trimmed slightly, so as to remove the projection in the line of stroke back to (*b*), at the same time roughing the surface and enabling the hammer to get a "grip": this being done the flank was successfully detached.

That this method was actually employed may be distinctly shown by the fact that many of the flakes, when placed together, show the trimming above described passing continuously across the base of both of them: thus they were chipped in a preparatory way more or less, or not at all, as occasion required.

One of the flakes, from which a smaller splinter has separated after it had reached the ground (the result of continued action of the blow which severed the flake from the block, and which, therefore, could never have been used), is much roughened by this chipping.

In arranging the flakes for the restoration, most of which had fallen to the ground at once, some could not be found, and this is explained by the fact that when imitating the use of the hammer above described, occasionally a flake flew to a great distance: one flew with a fearful whirr a distance of over 60 feet; doubtless this incident occurred to the old men. Notwithstanding that these flakes, on their first exhibition, were at once identified by a very high authority as having been "used," it is evident that the chipping at their bases is not the result of wear, but is merely a detail of manufacture.

I was enabled, by a careful examination of the surface, to see from the disposition of a heap of flakes, which lay divided by two slight lines and other signs, that the operator *sat* on the sand with his legs but slightly apart.

Sometimes stones nearly of the size and shape of the implement required to be formed were selected, and the crust removed wholly or in part from the surface. It does not appear that any of the crust was retained for a purpose, as in almost every case where the chipper was sufficiently skilled the whole was removed. I have seen many spoilt tools broken, in the apparent endeavour to remove some such blemish, which were otherwise perfect.

Since the Crayford find I have met with several floors where men wrought, and in one, which I succeeded in keeping somewhat to myself for a time, I observed some fresh details.

This was at Northfleet; it, like the last, was a river beach, perhaps dry in summer and subject to floods;—though, subsequently to the deposition of the refuse, some of the ground has been pushed about by ice, yet the immense quantity of flakes (cartloads), and other signs of man's occupation, furnish abundant evidence that he lived near, and worked on the spot.

These flakes are of all sizes, from over 3 lbs. in weight to a grain or two. Some are of great age, and have travelled far or lain long kicking about on the shingle, while others are as sharp as if made to-day; of the latter, some are clumsy, and some long, thin, and very straight.

Besides the ordinary method of chipping, that is, of hitting one stone with another in a manner not requiring much technical ability, at this spot a hammer was employed (fig. 6) which I have not noticed elsewhere. Many stones (flint) were found whose characteristic may be summed up by saying that they were pointed (and *the* point much used). In their best form they resembled kites, though they frequently were but long flints (a not unusual form), chosen for their weight and the possession of a good point, which, if not existing, was trimmed up; in weight they ran up to 10 lbs. Some of them were, however, not strictly pointed, but broken obliquely to the length, the part used being the projecting edge.

At this place, in the ordinary way of making a hâche, a stone was shaped and finished at the butt; in finishing the tip, however, by means of striking longitudinal flakes from a small surface left at that end, a heavy, sharp-pointed hammer was needed for the exact delivery of the blow, such as those before described. When the blow was true, and the tilt of the surface right, all went well; but it was not always so, and by means of spoilt implements I am able to show that the tilt was not always rectified, or the blow delivered with exactitude. Thus the striking off of too thick and large a flake, and the consequent spoiling of the implement, sometimes happened. This may have occasionally resulted from the hammer being worn out.

Another mode of manufacture largely depended on these sharp-pointed hammers. A flint stone being selected, and trimmed coarsely round the sides, was worked on its upper surface into the form of a flat dome; then from one end the whole of this prepared surface was detached by a single blow (fig. 5), producing, when the operation had been well conducted, a "turtle-backed" flake, with a flat surface on the other side (figs. 7 and 8).

In this and the before-mentioned uses of this kind of hammer, it is remarkable how much preparation and labour depended for its ultimate success on adroitness in the delivery of a single stroke! Many flakes were worthless, and were cast aside, but of those which were retained as suitable, two uses were reserved. Some were trimmed round the edges, mostly at one end and the sides, the other end or some part being left untrimmed, as if left for handling without inconvenience. This trimming was not needed so much at first when exquisitely sharp, as afterwards when the edge was lost by use. The trimming is invariably on one side alone (the raised one). I have called these "turtle-backed scrapers" (see figs. 7 and 8).

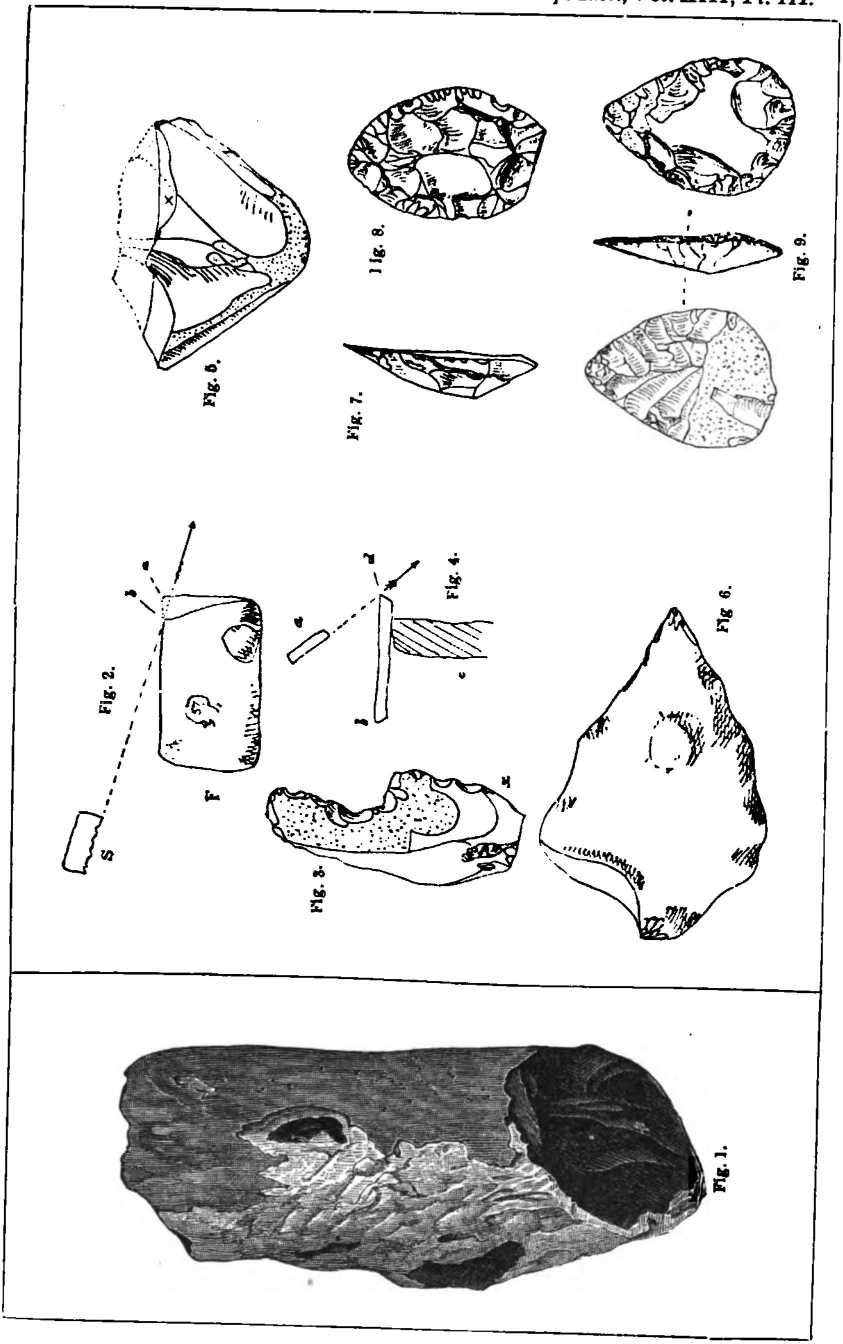
I think that though trimmed to keep the edge sharp, they would be less efficient than when new. These stones, which might equally be skinning implements, or sleeks (slicks) for dressing skins, were admirably adapted for the first purpose.

An ordinary flake, used to skin an animal, would as frequently cut upwards through the skin, as down on the bones or subjacent tissues, and would be less governable and more dangerous to the integrity of the skin in proportion to its sharpness; but these turtle-backed flakes, held with their rounded (or bevelled) sides towards the skin, could only cut *downwards*, and if they slipped could not perforate or injure it, a matter of extreme importance in those times. For the second use, that of currying and scraping, it being a less delicate operation, they would be well fitted.

A large number of the flakes at Northfleet showed signs of having been "worked." Some were what are called round or thumb scrapers, others present a straight edge, and some resemble the so-called hollow scrapers, and doubtless many might have been used for scraping bone and wood into shape. On examination, however, it is perceived that most of these implements show all the chipping to be on one side only, that it is sharp and unpolished, the hollow is very wide, and placed much to one end: these points do not agree with the shapes or uses of scrapers. They are not scrapers, but *knappers* (fig. 3). In consequence of this surmise, whilst trying to make a flat flake into a round scraper with another simple flake, I found that by resting one horizontally on a point of stone or wood, and striking it with the edge of another in a direction downwards, and slightly away from me, I could easily imitate to perfection many found at Northfleet, while on a repetition of the operation with the same knapper, I found its action improved, until at last it was difficult to tell the original from my own by the form alone.

So necessary was the deep hollow to success in their use that flakes were chosen which had a slight accidental hollowing. Some were left-handed in use. Their weight runs from about an ounce up to 8 lbs., and apparently the large ones must have been used in making hâches, some stones presenting signs of such treatment. It appears likely that the turtle-backed flakes were trimmed by this means occasionally.

I have never found any stones, other than flint, that have been used for the purpose of knapping or striking off flint flakes on river-banks, though tough pebbles of quartz, sandstone, &c., are common enough, and when these have presented signs of wear it was of that kind resulting from pounding some comparatively soft substance on another stone. I obtained the tools exhibited from the beds with my own hands; in truth, had I not done so, I should not have considered them worthy of the attention of this Institute; and I felt the necessity, on this occasion, of being able to say this, even if it entailed the omission of a few better examples than those present.



FLINT HAMMERS, WITH ILLUSTRATIONS OF THEIR USE.

The restriction which I thus placed upon myself has prevented some further observations being made, of an inductive and experimental nature, on palæolithic as well as later stone-working.

Description of Plate III.

Fig. 1. Stone hammer from Crayford; 3·8 inches long, 6·7 inches in circumference.

„ 2. Diagram explanatory of the use of the hammer (fig. 1). S represents the hammer, and F the block of flint.

„ 3. Flat flake of flint chipped by use into a hollow on one edge; there are no signs of chipping on the other side. This is a good example of the common form, the larger ones are less elegant.

„ 4. Diagram representing the manner of using the flake (fig. 3). It is held (the worked part upward) by the right hand at *x* in the position *a*. Another flake to be trimmed is held by the left hand at *b*, resting on a piece of wood; *b* being struck at *d* by the downward motion of *a*, the chips fly from the unopposed surfaces of each flake.

„ 5. A block of flint trimmed at the sides and at the top, where the form is indicated by dotted lines. This upper part is struck at one blow, at the spot marked × by fig. 6.

„ 6. A hammer, which was used at the pointed end, to ensure accuracy; the blunter end may also have been used. This is the most usual form.

Figs. 7 and 8. A tool made from a flake resembling the upper part of fig. 5. The flat side is left unworked; the other is trimmed to a regular form, and served as a slick or skinning implement.

Fig. 9. Also made from a flake like the upper part of fig. 5. It is, however, worked on both sides into a hâche; this tool is in admirable preservation.

N.B.—The above outlines (figs. 2 to 9) are drawn from actual specimens, on a scale of one-fourth natural size (linear).

Discussion.

Mr. W. G. Smith drew attention to the fact of quartzite pebbles, with abraded ends, being found in neolithic positions, such pebbles being generally accepted as hammer-stones, for flaking and pounding. Quartzite, he said, was specially useful for this purpose, being hard and tough, whereas flint is brittle. Mr. Smith exhibited quartzite pebbles, with the ends abraded off, from palæolithic positions, and he said if they were accepted as hammers when found with neolithic objects they had an equal claim to be considered hammers, when found with palæolithic implements. Mr. Smith exhibited some finely chipped palæolithic implements, and said it seemed impossible that such minute flakes had ever been detached from the tools by hammering at all. He believed all the small flakes were pushed off, as some savages now push off small flakes in making stone tools. In support of this he referred to the neolithic tools, termed "fabricators" by Dr. John Evans, and said that tools of a very similar character were found in palæolithic gravels: some of these he produced, and said, if the former small tools were used for tapping and pushing off small flakes, it seemed reasonable to consider that the palæolithic examples were used for a similar purpose. He agreed with Mr. Spurrell that hammer-stones of flint were often used in palæolithic times, and anvil-stones, as described by Mr. Spurrell, exhibiting distinct marks of percussion from hammer-stones, he had many times seen on the palæolithic floor discovered by himself at Stoke Newington Common.

Professor FLOWER, Professor BOYD DAWKINS, and Mr. PARK HARRISON took part in the discussion, and the author briefly replied.