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WILLAMETTE METEORITE

BY

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End view of meteorite.

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(Presented before the Academy, March 14, 1904.)

This most interesting meteorite, noble in size and wonderful in physical features, was found near the border of Clackamas County, Oregon, in the autumn of 1902. At this point in its course the Willamette River, 80 miles south of its junction with the Columbia, runs between high banks of sedimentary rocks. At Oregon City, 16 miles south of Portland, these banks come as cliffs down close to the river, which on the western side they follow southward for three and one-half miles to the town of Willamette. This meteorite having been found two miles from this town (to north-west) I have given it the name, as above, of Willamette Meteorite. Its exact locality is Lat. 45° 22′ N, Long. 122° 35′ W. The region immediately surrounding is a series of hills, distant foot hills of the Cascade Range, with their steeply sloping sides cut into by streamlets flowing into the Willamette. One of these streams is the Tualitin. On a hill-side, three miles above the mouth of the Tualitin, fell, apparently centuries ago, the Willamette siderite, the third largest iron meteorite in the world. The region is a wild one, covered by a primeval forest of pines and birch, little visited and largely inaccessible. Here, on the spur of the hill in a small level area, lay the great iron mass, lightly buried in soil and the carpet of accumulated vegetable debris. In the valley, half a mile away, there lives with his family, a humble, intelligent Welshman, Mr. Ellis Hughes. He had formerly worked in Australian mines. He had with him in 1902, a prospector named Dale, and together they roamed over the hills seeking minerals. One day a blow on a little rock projecting from the soil showed it to be metal. They dug and found its great dimensions; also that it was iron. It was on land which they learned belonged to a land company. For some months they kept the find a secret, hoping to buy the land on which the "mine" was located. Some months later they ascertained, in some way, that their supposed iron reef, which they had found to be but ten feet long and a yard or more deep, was a meteorite. They became more secretive than ever, and covered their find most carefully.

In August of 1903, Mr. Dale in the meantime having left the country, Mr. Hughes conceived the idea of bringing the great iron mass to his house, a distance of nearly three-fourths of a mile. This seemed an almost impossible task, he having only his son of 15 years and a small horse as motor power. But he was an old miner, full of mechanical resources, and also full of pluck and energy. With infinite pains he fashioned a simple capstan with chain to anchor it, and a long braided wire rope to roll up on it, as his horse traveled around it as a winch. Then he fashioned an ingenious car with log body-timbers and sections of tree trunks as wheels ; also some heavy-double-sheaved pulleys. By wearisome blocking-up and leverage he succeeded in capsizing the great mass directly upon the car and lashing it securely. (See plate 13). Then he stretched out his hundred-foot hauling wire-rope, attached one end of it to the car and the other to his staked-down capstan, and started his horse going round. The sequence of effect to cause followed ; so did the meteorite. The great mass moved slowly, for the ground was soft, and, even with boards put under them and constantly changed, the wheels sank deep into the mud. Some days they moved little more than the length of the car (which was that of the mass itself); on others they passed over ten, twenty, or (one day) fifty yards of their toilsome road. At last, after three months of almost incessant toil, the giant meteorite reached Hughes' own land, where it now rests. It was a herculean struggle between man and meteorite, and the man conquered. It is unpleasant to have to record what followed.

The Hughes, father and son, had for these months worked unobserved in the dense forest. Their nearest neighbors, a mile away, do not seem to have been aware of what they were doing. But when the great find was announced, people came trooping up the little valley, first from near-by Willamette, then from Oregon City, and then from Portland, to see the celestial wonder. News soon came to the Portland Land Company, and they promptly claimed the meteorite as having been taken from their land. Hughes refused to give up possession, which latter, he believes, is a strong point in the matter. So a suit at law has commenced, with all prospects of a stoutly fought legal battle. The suit should come off during the coming spring, but it may likely be delayed. Public opinion is divided as to the probable outcome ; but sympathy lies mainly with Hughes, the finder of the mass, and the only man recorded in common life or among scientific collectors as having run away with a 14-ton meteorite.

The newspapers of our country had for several months of the past autumn and winter noted this Oregon meteorite in a desultory manner, but their stories seemed exaggerated, and were not generally credited. In February I decided to visit the distant locality and investigate the matter. A four days' railroad trip put me upon the ground. To make my further description more clear I must say that before my arrival Mr. Hughes had unloaded his car, tipping off the great meteorite over upon its side. Thus the first three cuts in this present article are from photographs which were taken when the meteorite was in its vertical position, still standing upon the car. I have every reason to believe that they were accurate in every way. Notwithstanding every favor extended to me by Mr. Hughes, the fullest scrutiny of the great mass was attended with great difficulties. The weather was wet, a cold rain falling every day that I was there. The mass was in the woods without shelter, and the deep mud and slush around it made kneeling to examine the lower surfaces almost impossible. My first work was to take full measures. These I will give in connection with its general outline as shown in the several cuts which illustrate this paper. Plate 13 (frontispiece) presents well the general truncated cone, or dome-like form of the mass. The measures which I took, and which apply to this, are as follows :

The extreme length of the mass, 10 ft. 3½ inches.
The extreme breadth across base, 7 ft.
The extreme vertical height from base to summit of dome, 4 ft.
The total circumference of the base is 25 ft. and 4 inches.

It will be seen by noting plate 13, that while the upper dome is a circle in its section, this is not true of the lower part, which from mid-height expands before and behind into an oval form. This is observable in plate 14, where the lengthening of the base into an oval becomes quite clear, with the rapid slope of the right-hand end and a more gentle slope of the left. But regarding the mass at a right angle to this, or an end view, the sides of the central dome part are seen to come to the base almost vertically, and with very little enlargement or flaring.

The meteorite has thus the form of a huge abbreviated cone, having its base on two sides so prolonged as to produce an oval, whose long diameter is one-third greater than is its transverse diameter. There are no angular outlines to the mass as a whole ; all, whether in vertical or horizontal section, is bounded by broad curves. At this point I may stop to say that as the meteorite lay buried in the ground, its base was uppermost ; in other words, the reverse of the position it held upon the car as shown in plates 13 and 14. This position, with the apex of cone buried below, is unquestionably the one which it held as it came through our atmosphere during its immediate fall. That the great mass changed sides as it lay in the ground on the flat area where it fell is not to be conceived for a moment. Its front face in its flight was the apex of the cone. All features of the surface harmonize with this view. The upper half of this apex as shown in plates 13, 14, is devoid of any striæ such as so often occur on the *Brustseite* of a stone meteorite. Nor are there here any well defined pittings. If these have ever existed, they are now completely effaced. This part of the great mass seems to have undergone but one change since it entered our atmosphere and there met the trials of intense atmospheric friction. The denuding influence of this may well be considered as having induced the generally round and even character of the upper cone, though no fine polish or striation remains. The one effect noticeable on all this area is the presence of little spots or patches from one to three or four centimetres in length, of material which seems more dense, and of a faintly deeper shade of color from that of the main mass. These appear over all the surface in question, sprinkled indiscriminately, without order or allineation. They stand slightly elevated above the surface, and might in loose terms be called scabs. I am disposed to think of these as representing flows of melted matter, which were once more wide-spread or continuous, but now show simply as patches. I will not enlarge upon this appearance, for the conditions under which I saw the mass were most unfavorable.*

Proceeding to examine the lower half of the cone, we have to notice three things : First there is a large border area, a border averaging eighteen or twenty inches wide, entirely around the mass, which is quite covered with the pittings (Pezographs) which are so common a feature on both iron and stone meteorites. These pittings

*I may be permitted to again remind the reader that, as I saw the meteorite after it was tipped off from the car, the cone end was down, and I could study it only while kneeling in the mud, holding an umbrella over my head in a heavy fall of rain and sleet, and with a temperature too cold to comfortably hold a pencil. The day will come when this cone—as indeed the whole meteorite—will be studied under more favorable circumstances.

are well defined and continuous, but are shallow. They are usually oval in form, with a greater diameter of from three to eight centimetres. They appear to have no distinct form or allineation ; and they meet and merge into each other with but a fuller, slightly pronounced crest between them.

A second feature in this lower half of the great cone is the series of round bore-holes, sprinkled irregularly all around it and more generally near the lower border. These holes, which are so notable a feature on the Cañon Diablo siderite, as also in the Tazewell and in the Youndegin (Australian) masses, are here beautifully sharp and well defined. They are usually nearly circular in section, one to three inches in diameter, and in depth ranging from three or four inches to an undefined depth. These holes, notably those of smaller diameter, are sometimes materially larger in their inner portions than they are at their outer orifice. This feature, observable also in the holes in the Cañon Diablo masses, seems to militate strongly, if not conclusively, against any theory of their existence being caused primarily by the boring action of the air in the meteorite's downward flight. They are undoubtedly due to the former presence of lengthened cylindrical nodules of troilites or some other sulphuret which have subsequently yielded to decomposition, and have generally dropped out. An interesting specimen in the Ward-Coonley meteorite collection is a mass, some 15 inches in diameter, of Cañon Diablo iron, with such a circular hole ; its orifice being open, while all the lower part is occupied by the still remaining troilite nodule. In our Willamette iron no less than nine of these holes pierce the mass from its upper surface quite through to the base below.

The third feature of this upper (brustseite) face of the Willamette iron is one which now makes it the most remarkable meteorite known to science. This is the existence of deep, broadly open basins and broad furrows or channels cutting down deeply into the mass. The basins are distributed alike over the lower cone area. The furrows reach vertically quite across this belt to the lower edge or base of the mass, whose border they break with deep channelling. These deep bowl-like cavities and furrows exist more upon one of the sides of the meteorite (the right hand side as the mass is seen from the rear in plate 14, figure 2) than upon the other. And, as fate would have it, that was the side upon which the mass, tumbled from the car by Hughes, lay when I visited it. But plate 14 gives a good idea of the surprising size of these cavities. I was able (working from below) to get a view of the somewhat heart-shaped and double cavity so prominent in plate 14, figure 2. Its length was about 19 inches, its breadth about 14, and its depth about 5 inches at deepest part.

Other cavities (some from their form might be called basins, others caverns) were of various diameter at mouth, 5 to 10 inches, and varied in depth from 4 to 12 inches. In all cases these cavities had their widest expansion or opening toward the apex of the cone, in the line of flight of the meteorite. At the right hand in figure 2, plate 14, are visible two huge furrows or channels. One of these, the smaller, I was able to reach as the meteorite now lies, partly by sight, partly by feeling. Its length was 26 inches, its average breadth 5 inches, with a depth increasing from front backward from 3 to 5 inches. The parallelism of these furrows, as well as the allineation of the holes before mentioned, is an observable fact; while equally observable is their pointing from every side of the mass toward the apex of the cone. Nothing can be clearer than that this has been produced by the tremendous friction of the densely compressed air through which the meteorite passed on its way to our earth.

The air, which was compressed in front of the mass to a density comparable to that of some solid substance, has flown back past the apex and the sides of the cone with a friction force almost inconceivable in its intensity. The air crowded in front of a meteorite having a velocity of 60 miles per second has furthermore been shown by physicists to have, by reason of its compression, a heat of over 5000 degrees Centigrade (9,000° Fahr.) a heat calculated to melt away any surface which it enveloped. It is to the melting, rubbing and chiseling effects of this air compression, with its following air-stream, that we may attribute all the glazing, pitting, hollowing and channeling which we have observed on the front side of the cone and on the flanging base of our great meteorite. That the melting should be more powerful on the upper (forward) part of the cone is easily conceivable. Also it is clear that the boring and channeling power of the air should be most exercised on the basal flanges, on which it more directly impinged. The effects are here colossal, and words would feebly express the emotion induced in seeing the great cone, with its torn, excavated sides. It seems impossible in theory, but the whole is made easily credible in seeing and studying the effect. With it all comes forcibly the thought of how "Reason will lead where Imagination does not dare to follow".

It would be a serious omission not to call attention to the possibility, and even strong probability, that the great mass has contained great nodules or even long cylindrical inclusions of some mineral softer and more easily yielding to attrition than is the iron of which it seems to be wholly composed. We know that inclusions of troilite are frequent in siderites, in some of which, as for instance, Toluca, Youndegin, Cañon Diablo and Bella Roca, they occur in masses of some volume. We suspect that the Willamette may contain such troilite inclusions, and that they may have both determined the position and have greatly enlarged these excavations. This is particularly true of the long furrows, two of which are so prominent in plate 14. In these, the upper part of the wall hangs over as a rim, leaving the tube or gutter, as seen from the side, larger within than in its outside exposure. These furrows, as well as one of the holes, gouge deep recesses out of the otherwise continuous border of the mass. As is noticeable in plate 13, the lower part of the cone rolls smoothly around to join its base.

At this point in our paper we leave the cone or brustseite of our meteorite; repeating here that the three cuts taken before our arrival show the mass upright; nearly the reverse of the way we saw it. Plate 15, figures 1 and 2, taken from either end, show well the relation of the great meteorite cone to its base. With them, notably figure 2, is first revealed the second series of wonders of our most wonderful and absolutely unique meteorite.

On the base of the mass we shall see added phenomena. Plate 16 shows the full surface of the base of the great meteorite—its length, ten feet; its breadth, seven feet. It will be seen that its original surface was slightly crowning; also that this surface was covered with well-developed normal pittings of great similarity of character in all its parts. The remaining areas of this surface are in every case thus covered. Furthermore we observe the striking manner in which the base of our mass was drilled and bored by the clean, round holes which we have already noticed as existing in moderate numbers on the brustseite. Counting only those which are of limited diameter, there are over thirty of them, varying from a half inch to two and one-half inches across, and from three or four inches to an unmeasurable depth. Indeed, quite a few of them which are near the periphery, pass completely through the mass, as we noted when describing the other side. One of these perforating vertical bores or drill-holes is seen at the base of the figures; the other two are visible toward the extreme left. The position of these upon the base, the rear side of the meteorite, argues strongly for their origin being due to pre-existent troilite cylindroid nodules. The inner trend of some of these bores is quite irregular, and the surface roughened with sharp, tortuous ridges. Some few of the holes join each other below, anastomosing, as may sometimes be seen in sections of long troilite nodules in the face of a section of siderite. In the frequency of these long round holes and their general distribution over all sides of the mass, our present meteorite quite resembles, though it surpasses in this feature, Cañon Diablo.

But our attention is strongly drawn away from these aerial features, to so call these effects which were created and completed by the attrition and erosion of the mass as it flew through our atmosphere in its fall to our earth. For we have before us, as shown in plates 16 and 17, and plate 15, figure 2, a most singular and astonishing group of concavities and caverns. Nothing can exceed the labyrinthine and chaotic outspread of these. They cross the mass from side to side and end to end. Yet they have no regularity of distribution or system of allineation. They make a confusion of kettle-holes; of wash-bowls; of small bath-tubs! One of the latter, crossing the mass diagonally, is three feet long by ten to fifteen inches across, and with an average depth of sixteen inches. Another, nearly circular, is two and one-sixth ft. in diameter and eighteen inches in deepest part. This one is quadrifid in its bottom; each of the four areas being a distinct basin, swelling gently up from its center to the sharp crest running between it and its neighbors. Plate 17, giving views of either end of the mass, show well the depth and the *scooped* appearance of these caverns. The rim of the meteorite on one side has been broken into by their continuation outwards. Plate 17, figure 1, shows how one channel passes through, opening a hole from one side of the great mass to the other. To describe these caverns individually would be impractical as well as useless. We recognize at once that we are not treating of an ordinary meteorite phenomenon. We are observing an action or effect of *decomposition*, carried to its most extreme degree. We are reminded of the deeply water-worn surfaces of limestone in certain caves. Of eroded blocks of gypsum; or, most of all, of the cragged protuberances of old coral rock. *These excavations in our meteorite are clearly due to the action of water.* This has not been an erosion, as have been the deep holes and channels of the other side of the mass. There are here no lines of flow, no connections in the nature or the trend of the depressions. We have to seek a different cause and a different mode of action. This is not difficult to find. It has been seen that this meteorite lay in its original bed, as it fell, with the conical end down, and the flat base upwards and quite level ; that it lay just below the surface of the ground in a soil highly charged throughout with vegetable matter, the accumulation of centuries under the falling leaves and branches of a primeval forest. Finally we remember that western Oregon is a region marked as a rain-belt ever since it has been known at all. Every condition was favorable to the decomposition of this great mass of iron, so situated that its surface was ever soaked with abundant water, and that water was heavily charged with carbonic acid, due to vegetable decomposition Under such conditions the oxidation of the mass would go on rapidly. The depressions would soon be initiated; these would fill with water, and thenceforth the work of dissolution of the mass would go on rapidly and with ever increasing area of surface and power of action. This is an action in which there has been no intermittence and no minimizing; for while the frosts of the short winter may have for a time yearly lessened the chemical action, the increased mechanical effects of freezing and thawing would have quite compensated in accomplishing the destructive work. It is especially noticeable in studying these caverns how certain portions of the surface of the mass have been left unaffected, holding to-day not only the original superficial level, but also retaining in fullest degree the pittings and all other markings which the mass had when at close of its flight it reached its bed. These areas of original surface stand as islands in the waste depressions of decomposition; and in the majority of cases the decomposition which has made the caverns, has also undermined these intervening areas. These latter thus stand on pedestals or bases which are hour-glass in form, dwindling from top downwards and from below up. Thus it occurs that many of the round borings noticed before and which are so prominent a feature in the view of the base of the meteorite now pass quite through with a short passage from the old surface into the latter formed basin or cavern. Incidentally we may mention that the corroding progress of this decomposition has eaten holes, usually quite irregular in shape and often large in diameter, through the walls between the several basins. No less than ten of these, varying from two to eight inches in diameter, may be counted. The most casual view of the sides and bottom of these basins show the entire difference of surface texture between them and the inside of the great holes and furrows on the brustseite of the meteorite. These basins have a rough, sandy surface, not for a moment to be compared with the rubbed-down, semi-polished inner wall of the air-worked hole. The difference of appearance is as palpable and somewhat similar to that which exists between a glaciated rock and a sawed or ground rock surface. Here is again the occasion to express the opinion that probably this immense and profound caverning of the lower sides of the meteorite has been in some important measure determined and intensified by the presence in the body of the mass of some softer and more easily decomposed material. Such, too, would be, as in the other case, considerable masses of troilite. Before, we invoked its erosive quality; now we think of the rapid *decomposition* of a sulphid in comparison to that of a mass of dense iron.

This great meteorite has shown itself to be quite unique in the distinct and essentially diverse phenomena which it presents. On one side, it offers us the greatest known instance of aerial erosion, helped by fusion. No such holes and furrows due to aerial attrition have been offered by any other meteorite, whether of the iron or stone class. While on the opposite side it gives us a case of discrete decomposition of aqueous cause, far beyond anything before registered on these celestial bodies.

It is a truly interesting thing to see these two phenomena, each so potent, yet each so different in nature and in origin, connected with the same mass of matter, acting upon it at two different epochs, yet producing results having such general likeness in appearance. In the presence of these marks of cosmic power, all other features of our meteorite seem to dwindle. Even its great size loses some of its impressiveness. The measures of Willamette which I have given indicate its great size and give it place in this respect with the three largest meteorites known to science, a compeer of Peary's Anighito and of the Bacubirito, although not of the length of the latter nor of the cubic contents of either. It is interesting to note that all the largest meteorites have been irons. It is doubtful whether a mass of stone of such great volume could have come to our earth retaining its cohesion and integrity through the destructive agencies attending its atmospheric passage.

In a study made many years ago by Reichenbach in which some problems of meteorite flights are elaborated, it is shown that a meteorite passing with a lessened velocity of 20 miles per second through our atmosphere, with its computed density at the height of ten miles above our earth, would undergo a pressure of 7,700 pounds upon each cubic inch of its front surface. Only iron would sustain such pressure, and even this, as in the beautiful instance of Cabin Creek, is irresistibly affected.

To the light given forth by the glowing melted surface, with that of the stream of ignited particles flowing away behind the flying mass, must be added the enormously greater light of pro- ambient air, itself heated by the compression mentioned. The light thus given out can be almost as little conceived of, as described. It is well known that the apparent size of any meteorite in its aerial flight is very much greater than is the real diameter of the solid mass. Numerous instances will be readily recalled where a meteorite (the part that fell) was but a few inches in diameter, while the same in its passage through the heavens appeared as a globe of several feet in diameter. Thus we have the astonishing light effects in well observed meteorite falls where the whole country for miles on either side of its course is illuminated with the light of mid-day. The Athens meteor (Oct. 18, 1863) is said to have thus momentarily lighted all Greece. How great and dazzling and wonderful was probably the illumination within a radius of many hundred miles when Willamette fell. With what aerial commotion, explosion and pyrotechnics must this great mass have traversed the atmosphere and screechingly sought its final home, "losing itself in the continuous woods where rolls the Oregon."

The weight of the mass remains to be determined. Its shape makes its cubing a little difficult ; and the difficulty is notably increased by the many and voluminous hollows. Assuming the average depth of these in the base at 10 inches, we may assume the total weight of the mass is probably lessened by fully one-fourth by reason of them. The mean of several careful computations, based upon numerous measures taken around the mass, and with knowledge of the specific gravity of the iron, makes the meteorite weigh about 27,000 lbs. or 13½ tons. Before many months have passed we may probably have the great mass on scales, and thus know its exact weight. If our above estimate is correct, Willamette ranks in weight as the fourth among meteorites known to science, the larger of the two masses of Chupaderos weighing about 15½ tons.

An etched section of the Willamette iron shows it to belong to the octahedral group and to that division (No. 56) which is designated as Broad Octahedrite Og. But this structure is somewhat dimmed by numerous small flakes of a very much brighter and more lustrous iron than are the kamacite blades, and seeming to have no regular or definite form—the largest of them having a diameter of not more than 6 to 7 mm. These plates, at least in part, are apparently hexahedral, as some of the larger ones show Neumann lines on their etched surface. The patches of plessite are decidedly small, but occasionally show the alternating layers of kamacite and plessite formerly known as "Lapham Markings." The taenite lines are plainly visible along the edges of the kamacite plates. There are numerous small troilite nodules from 1 to 3 mm in size scattered promiscuously throughout the section, and a few rod-shaped ones 1 mm in width, and in some instances up to 15 mm in length. The largest troilite nodule found in several sections was 28 mm in diameter. It incased several small patches of the nickeliferous iron. No schreibersite is apparent to the eye, nor would it be expected from the small amount of phosphorus found in the analysis of the iron. The exterior of the mass in our possession is of a dull reddish brown color, much oxidized, with a tendency to scale in small flakes. The fractured surface of this iron is much more coarsely granular in structure than is that of any iron with which I am familiar.

Perhaps more about the inner structure of the iron may be developed as the mass is further sectioned.

The above observations on the structure of the Willamette iron are made by my assistant, Mr. H. L. Preston, who has had my small mass (a few kilogrammes) in hand, in Rochester, for section.

Two analyses of the Willamette iron have been made for me; one by Mr. J. M. Davison of the University of Rochester; the other by J. J. Whitfield of Philadelphia. We give these below:

DAVISON		WHITFIELD	
Iron, - - - -	91.65	Iron, - - - -	91.46
Nickel, - - -	7.88	Nickel, - - -	8.30
Cobalt, - - -	.21		
Phosphorus - -	.09		

The specific gravity of the iron is 7.7.

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FIG. 1. Side view, showing hole piercing the base.

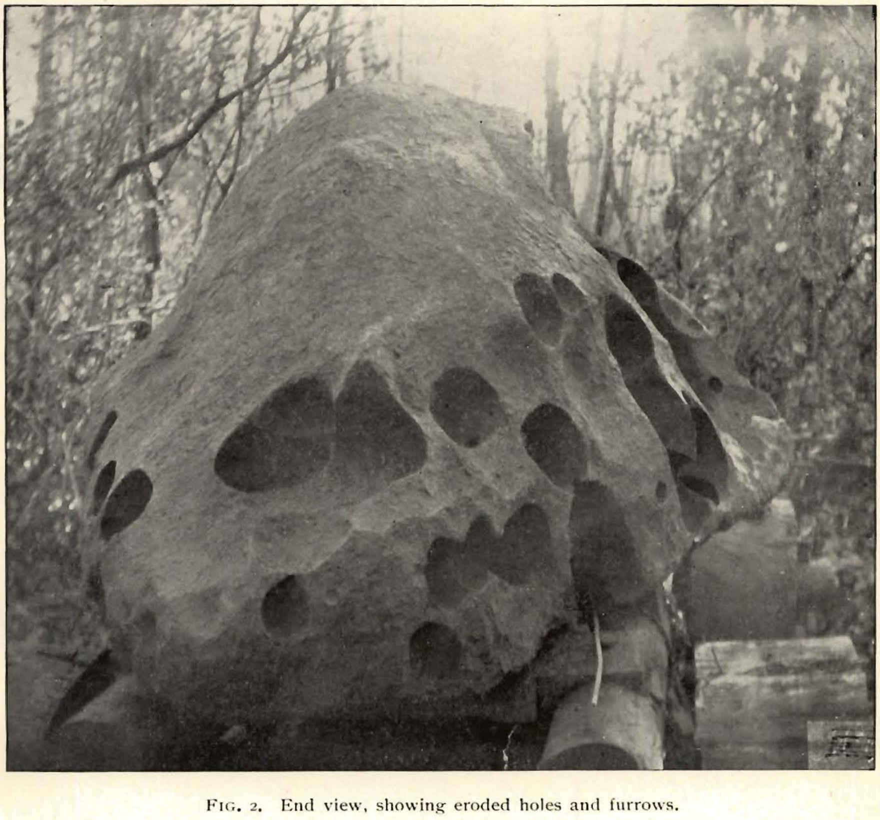

FIG. 2. End view, showing eroded holes and furrows.

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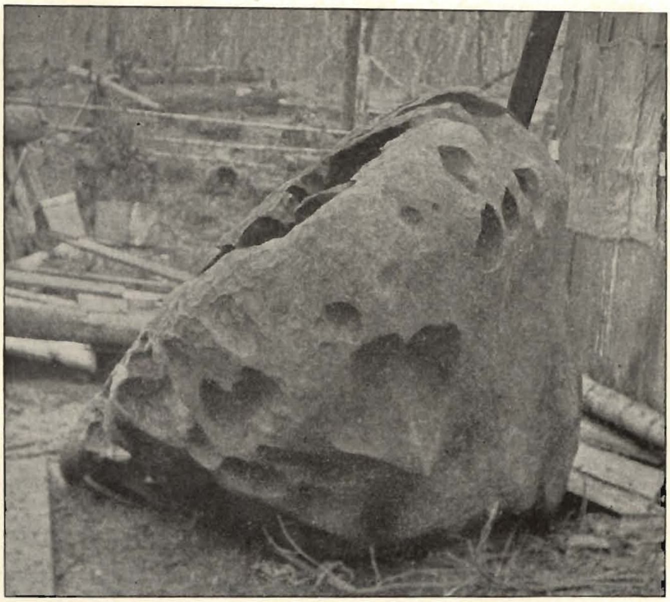

FIG. 1. North end view, meteorite capsized.

FIG. 2. South end view, meteorite capsized.

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FIG. 1. Full view, lower side of meteorite.

FIG. 2. Full view, lower side of meteorite.

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FIG. 2. Area of north part of base.

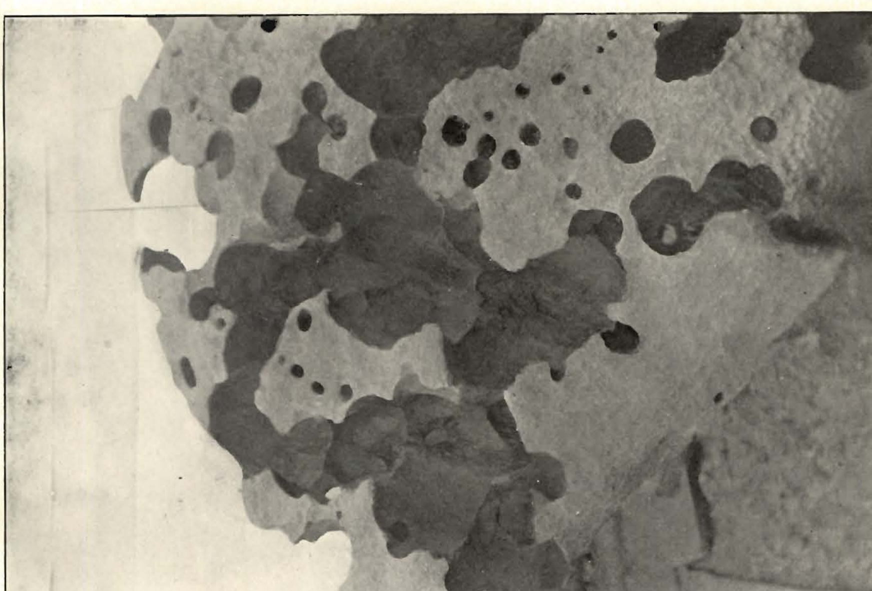

FIG. 1. Area of south part of base.

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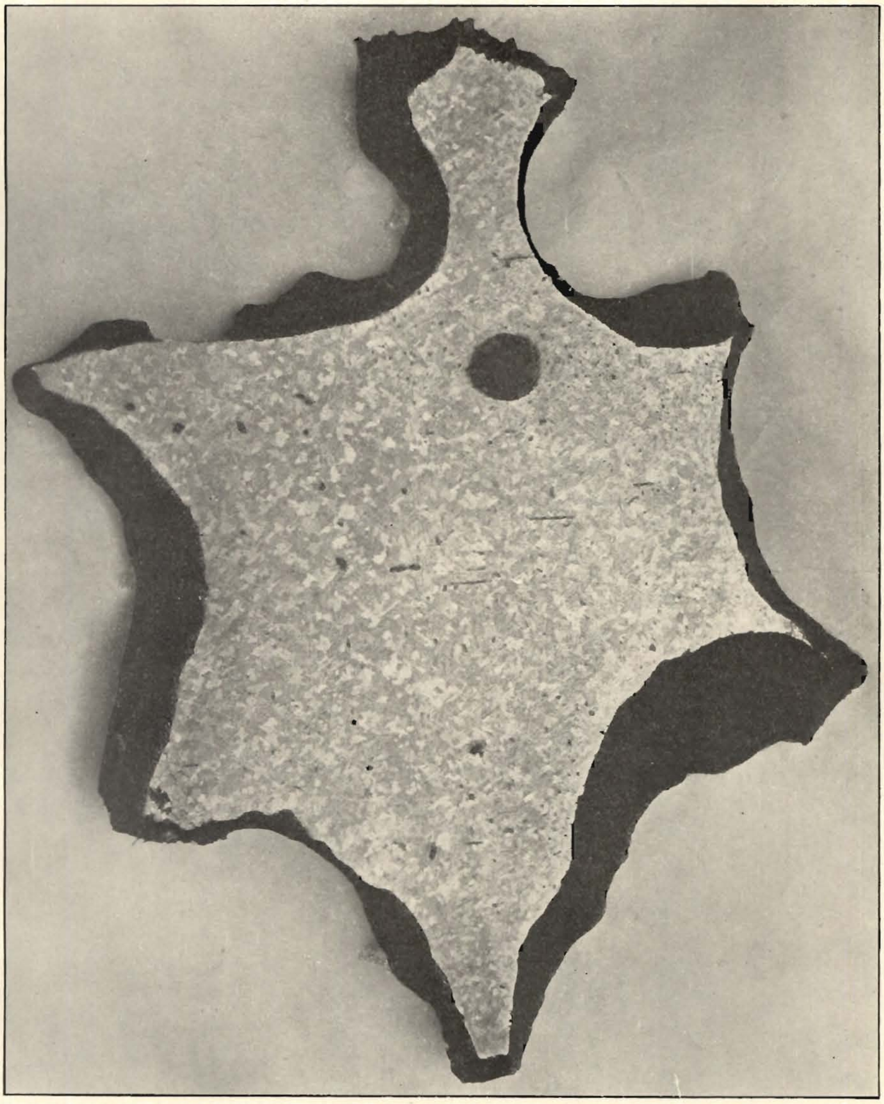

Etched section, ½ actual size.

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