PROCEEDINGS OF THE ROCHESTER ACADEMY OF SCIENCE
VOL. 4, PP. 193-202.

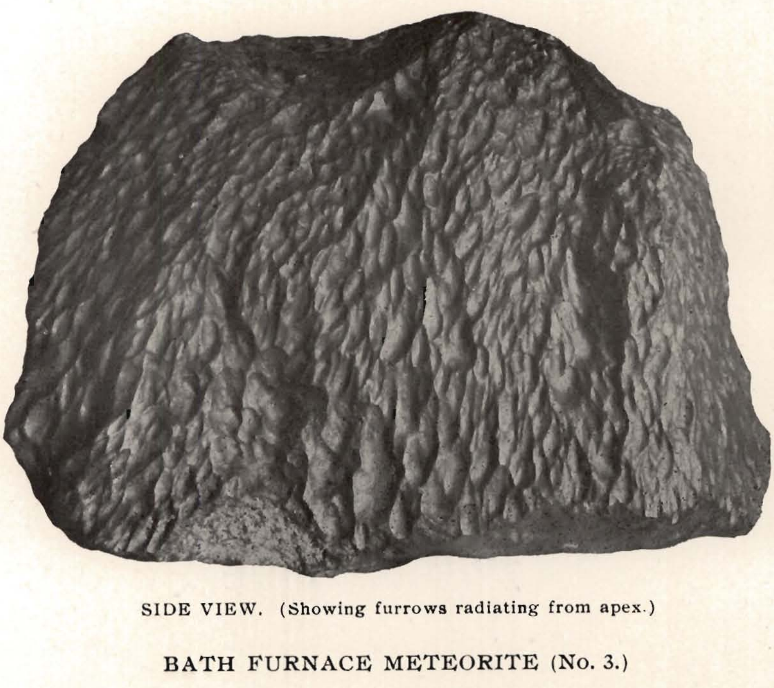
BATH FURNACE AEROLITE

BY

HENRY A. WARD.

ROCHESTER, N. Y.
PUBLISHED BY THE SOCIETY,
AUGUST, 1905.

FRONT VIEW OF THE MASS.



SIDE VIEW. (Showing furrows radiating from apex.)

BATH FURNACE METEORITE (No. 3.)

HENRY A. WARD.

PROCEEDINGS OF THE ROCHESTER ACADEMY OF SCIENCE

VOL. 4, PP. 193-202, PLATE 19. AUGUST 21, 1905.

NOTES ON THE BATH FURNACE AEROLITE.

By Henry A. Ward.

(Read by title before the Academy February 13, 1905.)

The passage of this meteor was first signalled in the early evening of November 15, 1902, high above northern Tennessee and Kentucky, and was seen as far north as Columbus, Ohio. Its course was north, 81 degrees east until its final fall in Bath county, eastern Kentucky, about 50 miles east of Lexington. Prof. Arthur M. Miller of the State College of Kentucky at Lexington, who recorded the fall in "Science" August 21, 1903, tells us that "The few residents of the region where the pieces struck seem to have been much startled by the blinding light and the heavy detonations accompanying the fall. They speak of the singing of the fragments, as they flew through the air, and of the sound made by their striking the ground, or hitting the timber on the knolls."

There were three distinct falls (noting only those of which pieces were found) all doubtless occurring simultaneously, but found at different times at points slightly separate.

The piece first found fell at 6:45 P. M. in the road in front of the house of Buford Staten, near old Bath Furnace, some five miles south of Salt Lick, and was found by him the following morning. It had cut a furrow east and west in the hard road about a foot long and five inches in greatest depth. It was about 8½x6x4 inches in dimensions, and weighed 12 lbs 12½ ounces. This piece was bought for me through the good services of Prof. Miller; and after cutting to show its inner structure, it was put in the Ward-Coonley Meteorite Collection.* Mr. Staten writing me of this fall said: "It sounded like a great buzz-saw ripping through a thick plank, and coming at me through the air."

The second piece was found one hundred yards west of No. 1.

*For description of this mass, see Am. Journal of Science (4th Ser.) Vol 16, pp. 316-319.

It was 2½x1½x¾ inch in dimensions, and weighed 223 grams. It was crusted over the entire surface, one side and one end being primary (original) crust, the other faces having a secondary coating, showing aerial fracture. This piece was cut through the center, and one-half went to the Field Columbian Museum at Chicago, the other to the museum of the State College of Kentucky.

The third piece (see Plate XIX) was found near the middle of May, 1903, about one and three-quarters miles south of the other two pieces, by a squirrel hunter, Jack Pegrem, whose attention was drawn to a scar on a white oak tree, some fifteen feet from the ground. Looking around he found, a few yards further on at the foot of a larger tree, broken roots and a hole beneath. Searching here, he found the great aerolite buried less than two feet, its apex crowded in among the roots, some of which had been cut through by the impact. Two other saplings in this vicinity, respectively about 100 and 300 yards farther east, were broken off by missiles coming from the west, and it is therefore probable that there were several other pieces besides the three here recorded, although search for them has been unsuccessful. This third piece has gone through the ordeal of a suit at law brought by the owner of the land upon which it fell, against the man who found it. The suit was compromised by the payment of several hundred dollars to the finder, in consideration of his relinquishing his claim. The mass was subsequently purchased by me, and is now one of the most notable specimens in the Ward-Coonley Collection.

It would be interesting to find the other pieces above mentioned whose existence is suspected, especially to see whether by shape or surface they would match either of the three known masses. None of these three are battered or bruised in any way by striking the earth, which is particularly surprising in the case of the largest, No. 3, which grazed the trunk of one tree and cut the roots of another before it came to rest in soft ground. But it is on this mass that the breaking off of pieces while still in the air is most noticeable. Several of these pieces must have weighed from one to three or four kilograms each. They came from two sides of the triangle, and were three inches in greatest thickness, and at least four in number. All three of the original masses of this aerolite are quite covered with a dense, black crust which is of two degrees—primary and secondary. The primary crust covers the entire surface of mass No. 1, two sides of No. 2, and all but one of the sides of No. 3, with the exception of the parts where, as mentioned, pieces have chipped off. These last faces or scars have, indeed, a crust quite covering them, but it is much thinner than the other, and through it appears the texture of the broken surface beneath. These areas of secondary crust attest to a breaking of the stone in the air while it yet had great velocity, and while it had still so great distance to fall that there was time for a second crust to form.

The base of mass No. 3, the largest single surface, has the usual thick crust which characterizes the rear, or Rückseite, of all well oriented aerolites. It has been protected from the pitting and furrowing effect of the rushing air, while all the results of melting have remained, not being swept away. On the opposite point or prominence of the front or Brustseite there is (as is usual on this form of aerolites) a very thin crust and bare of all pittings.

This third mass of the Bath Furnace is one of the most completely furrowed and definitely oriented aerolites known to science. We know no stone of American fall which equals it in this respect. The furrowing of the front side is most complete. These furrows radiate from the apex in all directions, covering that surface and streaming back upon and over all the sides. The regularity of their trend is most interesting as showing the steadiness of the mass in the air and the constancy of its axis in an orientation which doubtless was promptly taken after it entered our atmosphere and was retained throughout its whole flight. It owed this steadiness to the fact that the shape of the mass accorded with the center of gravity, or the mass was well centered, and thus it was gripped and held firmly with no shiftings or rotation. We may note here that the aerolites of a more or less spherical form have the pittings and the orientation less marked. It is well known that meteorites, both stone and iron, almost without exception show themselves to be fragments of most irregular shape, torn from larger masses of the same material, but always having their corners more or less rounded. But these same masses primarily were angular in shape and often with sharp thin edges. When these struck our air and met its resistance, they doubtless *wobbled* much to right and left before erosion wore them into poise and a steadiness of gait. We have all noticed the ricochetting of shooting stars in the upper heavens. This has been generally attributed to their glancing, due to irregularity and flatness of form. Very soft is the extremely attenuated air into the upper layer of which a meteorite plunges in its downward flight, as it leaves the realms of outer space; but after the first fraction of a second the mass is opposed by great density of the air through which it cleaves its way only by its momentum and with ever increasing friction. No longer is the mass passing through a gas, for its flight has changed the air by compression into a virtually solid substance. The enormous pressure exerted upon a flying body by its compression of the air through which it passes has been estimated by physicists. They tell us that a body traveling 20 miles a second through the lower atmosphere would have upon it a pressure of 77 cwt. per square inch. Reichenbach, Jr., has shown that the air crowded in front of a meteorite with a velocity of 40 miles per second would have, by reason of its compression, a heat of over 7000 degrees Fahrenheit—a heat calculated to melt away any surface which it enveloped. It is to the melting, rubbing and chiselling effect of this air compression that we may attribute all the glazing, pitting, hollowing and channelling which we find on the front and sides of meteorites. As may be expected, the iron meteorites have been less rapidly eroded than the stones. They, too, are apt to be in large pieces. Only iron would withstand such a pressure, stones breaking with the tension. The extent of this erosion will depend much upon the composition of the stone, also upon its form. The worn-off particles fly off, making at the same time great streams of sparks. Probably by far the larger number of the masses are entirely worn away. The wonder is that any part of the stone remains.

It is probable that the external combustion of a meteorite ceases before it wholly loses its cosmic impulse; its incandescence and luminosity ceasing also. This great heat is confined to the exterior of the mass from which the melted particles are instantly brushed away as they form. It thus results that the fiery, flaming mass is in fact mainly cold. It brings with it the temperature of the celestial spaces, which has been estimated at 504 degrees (Fahrenheit) below zero. The aerolite Dhurmsala in India, Pegu in Burmah, and Lissa in Bohemia were thus cold when they reached the earth. In the Pultusk meteorite shower which fell during a snowstorm in January, 1868, one of the stones weighing four pounds was found covered with light snow ten minutes after the fall. Orgueil, although carbonaceous, did not have its interior in the least affected. The heat of meteorites at moment of fall has ever been greatly exaggerated in common narration. It is a most frequent thing to have a record of their being too hot to handle even several hours after the fall. An examination of meteorite literature in the publications of the past century has shown me but two cases among the irons—Agram and Mazapil—where a heat making it difficult to handle the mass at time of falling has been recorded; and in but two cases that I have found in the description of nearly two hundred aerolites has any claim to more than simple warmth at time of fall been made. One might expect this from an aerolite of very loose texture, which would allow rapid penetration of the heat enveloping it when in air; or from an iron with its more ready conductivity. With trivial exceptions these accounts of hot meteorites belong to sensational newspaper stories. There has certainly been heat in melting intensity on the outer surface of the mass, but it has been kept from penetrating by the intense cold of the interior. The Widmannstäten figures of irons would have been destroyed by intense heat. Cohen explains in this way the change of N'Goureyma siderite from an octahedral iron to an ataxite.

There remains to be noticed the breaking up of the stone in the air. Everything, astronomical inductions as well as physical facts, certifies to the greatly varied size of the cosmic fragments which enter our atmosphere. These variations doubtless existed primarily. But while still in space, circulating in cometary orbits of long extent, there must have been many collisions both among members of the same stream and with those of other streams, and probably, too, with some of the streams coming, as has already been noted, from opposite directions with opposite course around the sun. Darwin (Geo. II.) has graphically described these streams as hastening ever onward with the same profuse variety of fragments, —great boulders, smaller ones like cobblestones, pebbles, gravel, and even sand—as may be collected at the foot of a rocky cliff. When such a stream chances to come within our earth's attraction and fall into our atmosphere, friction commences with ensuing attrition, heat, and luminosity. The myriad finer particles are promptly reduced to such comminution that they henceforth fall slowly, reaching our earth with imperceptible fall as cosmic dust. The smaller fragments flash out as shooting stars, none of which, says

Herschel, have a nucleus much larger than cherries or chestnuts. All these are in the upper air, from 70 to 100 miles above us. The larger masses pass on and undergo the terrible ordeal of heat and erosion; under which the largest pieces are promptly reduced to smaller ones, perhaps not one tenth of their original size, and the smallest pieces are worn out and dissipated entirely. Probably no aerolite which entered our air smaller in size than the human head ever reached our earth. The siderites have unquestionably resisted better the forces of attrition, but of all the many million meteorites (scientists' estimates range from ten to twenty million) which enter our atmosphere daily, probably less than a score reach our earth, either as large or as small pieces. We do not sufficiently recognize the beneficent service to us which is performed by the cushion of protecting atmosphere above our heads. It may be said incidentally that the meteorites, both iron and stone, which reach our earth and have been collected run in size from tiny bodies no larger than peas all the way up with almost even gradation to blocks two or three feet in diameter. The latter is the limit of the stones, the largest one on record being the Long Island, Kansas, which is nearly three feet long and weighs with all its fragments 1244 lbs. The present specimen, Bath Furnace No. 3, is believed to be the third aerolite in weight (177¼ lbs.) ever found on our hemisphere. Iron meteorites run much larger. The two largest which have been weighed are the Mexican Chupaderos weighing 15½ tons, and the Cape York Anighito, weighing 36½ tons. Bacubirito, an iron meteorite, still lying in a valley of the Cordilleras in the State of Sinaloa, Mexico, is longer and wider than either of the preceding, but not so thick as the Greenland mass. When this Sinaloa mass is weighed, it will be known which country, Mexico or Greenland, has to its credit the heaviest meteorite so far known on our earth.

Once more let us look at our meteorites in the upper heavens. They have entered our atmosphere as rough, angular masses which would at first, for a short section of their flight, have a rotating movement imposed upon them by the air's resistance. Then, their angles and their projections being worn away and their center of gravity established, their course becomes direct, and is marked by a long, unbroken stream of light, with sparks flying through and out of it. The head of this stream is larger than the part which follows, and all are greatly larger than the meteorite kernel which they enclose and conceal. The size and the brightness of this trail of fiery sparks is indicative of the immense erosion and reduction which the solid meteorite is undergoing. The greater size of the front or head of the trail is due to the piling up in front of air heated by compression to a state of incandescence. At intervals, sometimes rare, sometimes frequent, but never regular, there are what both the eye and the ear lead us to call explosions, a sudden throwing off of sparks in all directions accompanied by a loud detonation. The explanation commonly given of this phenomenon is misleading, if not wholly incorrect, namely, that the breaking of the mass with violent detonation results from the intense heat upon the outside due to the friction, together with the extreme cold of the inner portions, thus causing unequal expansion, and a cleaving away of the outer portion from the inner, thus breaking up the mass. As a theory this may be reasonable, since we see such superficial flakings in intensely heated blocks of granite and other dense rocks. But there are reasons for seeking other explanations of these detonations. As a fact the pieces of aerolites which show fracture in the air have not at all the form of flakes or conchoidal plates. On the contrary they show almost invariably as pieces broken more or less through the middle of a larger mass. This is true of the hundreds of pieces in a meteorite shower, as of Mocs, Pultusk, or Winnebago Co., where the surfaces bearing a secondary crust show clearly the fracture through the middle of the mass. Further, in the case of the Butsura (India) aerolite the several pieces falling one or two miles apart were found to fit together, and the fractures were deep through the mass, not superficial. In short, the explosion theory for meteorite aerial dismemberment is not sustained by the facts registered on the fragments themselves.

Our explanation is based on what has been said above of the great compression of the air by the stone passing through it. This compression generates a resistance and a density of air comparable or even superior to that of the stone itself. To this resistance the stone often yields and breaks, as would a stone crowded increasingly against an immovable and impenetrable wall. In the breaking of the meteorite the air in front falls into the vacuum following behind with instantaneous effect, and thus the detonation follows immediately on the breaking. In other and probably frequent instances the meteorite turning in the air, owing to change of form by erosion, allows the vacuum behind it to fill suddenly, and detonation ensues. In none of these instances can the phenomenon be properly called an explosion. Scientists would seem to be agreed that in describing this breaking or bursting of a meteorite in its course, it shall not be called an explosion in the sense of being due to a force acting on the mass from within outward. But they have not come to an agreement as to how the dismemberment and detonation are really caused. We do know that the final bursting is a phenomenon in that part of the meteorite's course where cosmic velocity is retained, for the fragments then thrown off have still time to acquire surfaces of secondary crust, which would almost surely not occur during any distance of gravitational fall. This means, then, a height of at least 30 miles, a height indeed which is accorded to the horizontal path of many bursting and detonating meteors. There has been a curious speculative theory originated by Haidinger, and practically accepted by Brezina and Doss, that there is a point "Hemmungs-punckt" as he calls it , where the falling meteorite finally loses its cosmic velocity, reaches for an instant a "Stillstand," and thence-forth is left solely obedient to the power of gravity. Galle who also accepts this theory adds to it a corollary, that the greater the original cosmic velocity of a meteorite the less the gravitational velocity with which it finally reaches our earth. It should be added that this point of loss of cosmic impetus will be largely determined by the angle between our earth's surface and the path of the bolide, and the consequent amount of aerial resistance which is to be overcome. We leave this subject with the single additional observation that in any clearly seen fall of a meteorite the detonation comes usually some seconds, often indeed, several minutes, after the fall, the sound coming at only 1100 feet per second, while the meteorite has traveled much faster. We have also the curious fact that when there have been several successive detonations it is the last one of these which is heard first, and so on back in the series.

The force with which meteorites strike the earth is quite variable, as we should expect from previous consideration of their relative motions. Meteorites have been known to strike on thin ice and rebound without breaking either the ice or themselves; while a 500 pound siderolite that fell at Estherville, Ia., on May 10, 1879, penetrated a stiff, clayey soil to a depth of eight feet. Another piece of the same meteorite, weighing 170 pounds, fell two miles distant and penetrated dry soil to a depth of only four and a half feet.

Recalling the date of its fall we observe that Bath Furnace is one of the Leonid shower of meteorites, whose stream the earth encounters yearly on November 14th and 15th. Although we seem to have been deprived of the main group of this stream which for many centuries passed us at intervals of 33 years and was due in 1899, but which some astronomers tell us has been permanently diverted by the pull of Jupiter, we still have a smaller yet respectable number appearing at the proper time. Possibly during the past 33 years the largest cluster of the stream has been dissipated and by attenuation more evenly distributed along its track. In any case it is interesting that so large a meteorite should have come to us in a star-shower so feeble as that of Mid-November 1902.

The rarity of a periodical star-shower furnishing meteorites to our earth, or the rarity of a meteorite fall occurring at the same date as the shower, has been frequently commented upon. The Lyrids and Perseids have indeed given no case of this concurrence. But the Andromedes gave us, Nov. 27, 1885, the siderite Mazapil. The Leonids had already three meteorite falls to their credit (Werchne Tzchirskaja, South Russia, 1843, Trenzano, Italy, 1856, Saline Township, Kansas, 1898), when on November 15th, 1902, Bath Furnace came hurtling down in a triple shower in the woods of eastern Kentucky. Prof. Farrington in describing Saline Township had drawn attention to the fact of its similarity in the leading features of its composition to the two previously fallen Leonids. And now we add a fourth, Bath Furnace, which, like its three predecessors is also a spheroidal Chrondrite, although of an intermediate type. The fine inductive work of Schiaparelli nearly half a century ago discovered the close and unquestionable relationship of the several periodic star-showers with different comets of known orbits. Thus the Andromedes are linked with the Biela comet, following its track and dropping off, as we have seen, the Mexican meteorite Mazapil as it came near our earth in 1885. And in same manner the Leonids are linked to Tempel's comet, and have dropped us four samples of the same in the last 61 years. H. A. Newton and others have pointed out the fact that all the comets had originally long, elliptical orbits, and that most of them came to us from interstellar space. Tempel's comet of 1866, which is responsible for our Bath Furnace aerolite, belongs now strictly to the solar system, having, as Kirkwood informs us, its entire orbit in the space between those of Mars and Jupiter. It was, however, originally of interstellar source, and has been captured by Jupiter and tied up to a shorter and more circular orbit, as have other comets to the number of nine. Whence the comet has brought this meteorite it would be interesting to surely know. If, as is most reasonable, from interstellar space, then our meteorite is indeed most wonderful. Interesting, too, that like one of our foreign steamers, it should have come into port exactly on the appointed day.

Returning to our aerolite itself we find on examination that its composition is a base of fine, compact olivine and enstatite, both silicates of magnesia, with abundant sparkling points of nickel iron. It also has numerous white and gray spherical chondri of like material distributed through it and breaking firmly with the mass. Its component minerals are thus allied to those of terrestrial volcanic rocks; but in common with other aerolites it shows nothing of the melted slag structure of lavas.

Stony meteorites apparently show us unchanged minerals from inner parts of the parent cosmic body, as suggested by their constantly anhydrous character and their feeble oxidation. That they bring us no new mineral elements would seem to point to their earthly origin. But spectrum analysis of the rays from other heavenly bodies indicates a similarity of composition of all bodies both from the solar system and from interstellar space. The varied direction of meteorites as they enter our atmosphere, notably the fact that some of them have an orbital motion contrary to that of the solar system, points to extra-solar origin.

A review of the chemistry of meteorites teaches us that they yield only those elements which we know to exist on our globe, and as they have not offered us a single new element we may justly conclude that the most distant regions in stellar space contain only a repetition in varying proportions and combinations of the same elementary substances as obtain upon our earth.