FOR THE INCREASE AND DIFFUSION OF KNOWLEDGE AMONG MEN

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A Falling Meteorite. From a painting made for this work by Benson B. Moore, under the supervision of the author

MINERALS FROM EARTH AND SKY

PART I

THE STORY OF METEORITES

By

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Head Curator, Department of Geology,
U. S. National Museum

PART II

GEMS AND GEM MINERALS

By

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PREFACE

This book is not intended for the specialist; rather for those who—whether or not engaged in other lines of work—are interested in the progress of science and in the method of its progression. It was with the latter particularly in mind that the narrative form was adopted for certain chapters. How a conclusion has been arrived at is, to the public mind, believed to be of as great interest as the conclusion itself.

George P. Merrill.

PART I

THE STORY OF METEORITES

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Head Curator, Department of Geology,
U. S. National Museum

CHAPTER I

INTRODUCTORY AND HISTORICAL

Far up in the remote and silent reaches of the sky there may be seen occasionally on almost any cloudless night a faint moving spark of light. Appearing suddenly and apparently from nowhere, it travels rapidly through a section of the sky, for a moment increasing in brightness, and then as quickly and silently disappearing. It is as though some unseen, gigantic, and sacrilegious hand had scratched a match upon the portals of the heavens. We *call* it a meteor, but what is it? It is possible that, as though in answer to the question, one of these mysterious objects may assume a more tangible form and come to earth, no longer noiselessly, however, but with a hiss, roar, and crash of thunder, brightening the heavens as a flash of lightning, and then as suddenly subsiding. Yet again we ask, what is it?

In considering this matter, let us first indulge in a few commonplaces concerning our planet and its surroundings. A background is needed for the story we shall attempt to tell.

Space, as we look out upon it during the day, imparts a sense of emptiness, of vacancy. It is only after sundown, and particularly when we look toward the Milky Way, that we begin to appreciate the vast number of bodies like our sun, which we call stars and with which we are associated. Photographs through telescopic lenses (Plate 1) vastly increase the impressiveness of the view, but even these fail to convey a complete idea of actual conditions. The stars, as stated, are suns; and some of them, no doubt, like our own, have planets, nonluminous in themselves, wholly invisible to the naked eye, and made visible with the telescope only by a slight and temporary dimming of the light when one happens to cross the face of a star under observation. These planets again may have still smaller bodies revolving in known and regular orbits about them, as our Jupiter has its moons. None of these is stationary, but all are progressing through space in a regular, orderly manner. The astronomer can tell with a fair degree of exactness their relative position a thousand years ago and what it will yet be a thousand years hence.

In addition there are untold millions of smaller bodies, the presence of which is wholly unsuspected by the casual observer. These, in seemingly erratic courses, are flying through space in every conceivable direction and at almost incredible speed. Giving no light by themselves, of a size too small to yield an appreciable amount of reflected light, it is only when in their wanderings they become momentarily luminous through contact with the earth and its atmosphere that they make their presence known.

Now every schoolboy knows that when he throws his ball it remains in the air only so long as the speed imparted to it is sufficient to overcome the attractive power of gravity. When this slackens, it falls to the ground. So with these various bodies which we have just considered. All are traveling through space at varying speeds and at rates well-nigh incredible, unthinkable to us even with our recently acquired knowledge of speeding airplanes and high-power guns. The writer once stood on the deck of a steamer opposite Indian Head, on the Potomac, and watched one of the enormous engines of warfare in actual practice. There came a flash, then a cloud of smoke, and later the roar of the report. Turning leisurely and looking down the river, there was seen in a few moments the splash of the projectile as, with propelling force spent, it yielded to the attraction of gravity and came to rest. Now the shell from this piece of ordnance had a muzzle velocity of some 2,700 feet per second; or, in round numbers, would travel a mile in two seconds. Startling as such speed may seem, it is slow compared with that of the so-called heavenly bodies by which we are surrounded and upon which, from our earthly viewpoint, we have been gazing. Our rotund earth itself is traversing its seemingly barren void at a differential speed of 19.8 miles per second. Our moon is traveling about our earth, the earth about the sun, and the sun in its turn about a greater sun, and it is through the fine adjustment of speed and gravitational attraction alone that they are enabled to hold their relative distances. It is speed, speed and mass, which holds the entire visible universe in its present seemingly stable form. But, one may ask, whence the speed?

> With what an awful world-revolving power
> Were first the unwieldy planets launch'd along
> The illimitable void!

writes Thomson in his *Seasons*. What, indeed, gave them this "awful world-revolving power?" This is a question we shall not attempt to answer. We are already beyond our depth in space—let us hasten back to earth and continue our story of the smallest and most insignificant of these celestial bodies, which are to be the subject of our studies. Whence their origin and the source of that awful power that launched them on their way is as yet known only in theory. Their destiny can, however, be foretold. Such are the laws of gravity that, whenever one of them comes in its wanderings sufficiently within the attractive power of a larger wanderer, it is drawn toward it and perhaps, like the moth in the flame, completely consumed. Astronomers tell us that each day 400,000,000 of them enter the earth's atmosphere, and that of these 20,000,000 are of sufficient size to form a shooting star, or *meteor*—a streak in the sky such as that to which attention was first called; but so great is their speed and such the resistance of the earth's atmosphere that even in the few seconds of their flight they become heated to the point of incandescence and even consumed. Occasionally —rarely—one is of sufficient size to survive in part and comes to earth, a scorched residual of stone or metal to which is given the name *meteorite.*

There are those who argue that our entire earth was built up by a process of accretion—an ingathering of these flying bodies. If so, time indeed must have been illimitable. "In the beginning" is pushed back beyond the possible reaches of human imagination; for it has been estimated from such scanty data as are available that the earth's mass is, at the present rate of incoming matter, increased by only some 93,000 tons annually, an amount which, if continued for 350,000,000 years and evenly distributed, would form a film of but one inch in thickness over the entire surface.

But enough of this. Let us consider an actual occurrence of one of these incoming bodies as given in the publications of the time.

On the evening of February 12, 1875, at half past ten o'clock, there suddenly appeared over northern Missouri, at a height estimated as fifteen miles, a bright light, seemingly emanating from a solid body which passed rapidly from the southwest to the northeast into southern Iowa, where, at an altitude of about two miles, an explosion took place, sending to the earth a shower of irregularly shaped stones varying in weight from a few ounces to many pounds and aggregating not less than 700 pounds. Accounts of the phenomenon as given by eyewitnesses are somewhat variable, though rarely contradictory. By one observer, the object was described as oblong in shape, with a train ten or twelve times the length of the body, giving an intensely brilliant light of crystalline whiteness at the center, fiery red on the bottom, and throwing out

PLATE 1

Looking into "empty space." The white spots are stars; the straight line a meteor trail. From a photograph. (Courtesy of Yerkes Observatory)

Fall of a meteorite in the midst of a field. (From *L'Astronomie*) red sparks and purplish jets of flame. To another, it was of horseshoe shape greatly elongated, the outer edge very brilliant, then a narrow dark space with a core of intense brilliancy, so vivid as to blind the eyes for a moment. Again, to an observer at the Iowa Agricultural College, it appeared in the form of an immense rocket with streamers flowing from the hinder part, the front being smooth and curved like a saber. Its color was at first brilliantly white, illuminating the sky like a flash of lightning, fading gradually into yellow, then to deep orange, almost scarlet, when it burst. The phenomenon was observed throughout a region at least 400 miles in length, from southwest to northeast, and 250 miles in breadth. The "explosion" mentioned gave rise to detonations so violent as to shake the earth and to jar the windows like the shock of an earthquake, and was compared by some to the discharge of a forty-gun battery. This was followed by a rushing, rumbling, and crashing sound that seemed to follow the meteor's path. The product of the fall, as already noted, was a large number of irregular fragments of stone, the largest of which weighed perhaps 120 pounds. They were mostly entirely covered with a black coating beyond question due to the fusion and sudden cooling of the outer portions of the fragments in their passage through the atmosphere. (Plates 3 and 5.) A feature of additional interest lies in the fact that but a portion of the meteor fell at this point. What seemed the larger portion continued on its way and, if it fell to earth, was never heard from.

This description, typical of many, will serve to illustrate the ordinary phenomenon of a shooting star and meteoric fall. It is not strange that such phenomena should early have attracted widespread attention. Neither is it strange that there should have been among those not actual witnesses of the event a considerable amount of skepticism regarding the fall of stones from the heavens. Like instances have, however, been recorded from very early times, and it is altogether probable that such Scriptural references as the following refer to similar phenomena:

> And the stars of heaven fell unto the earth, even as a fig tree casteth her untimely figs, when she is shaken of a mighty wind. (Rev. vi, 13.)
>
> And there fell a great star from heaven, burning as it were a lamp. (Rev. viii, 10.)
>
> And there appeared another great wonder in heaven; and behold a great red dragon, having seven heads and ten horns, and seven crowns upon his heads.
>
> And his tail drew the third part of the stars of heaven, and did cast them to earth. (Rev. xii, 3, 4.)

Satisfactory pictorial illustrations of such events are not abundant, for the simple reason that the period of flight is too brief for even the most experienced of snapshot photographers or rapid delineators and that the phenomena are comparatively rare. The fall invariably occurs at unexpected moments and in unexpected places and few are prepared to view it with the calm and discriminating eye which scientific accuracy demands. Those illustrations which have thus far been published were unquestionably drawn from memory, aided in some cases by a facile imagination. There is about them, however, nothing incredible, and it is felt that the composite view given in our frontispiece may be accepted as conveying an approximately correct idea.

The description of the Homestead, Iowa, fall, from which we have so fully quoted, is a modern one. It is that of a fall which took place many years after the possible fall of "stones from the sky" had become an established fact. Let us go back and cite an earlier occurrence and note the effect upon the general public as well as upon the scientific mind, and also the gradually expanding views held as evidence was presented by succeeding falls. Naturally but few of the many can be considered, and the reader is referred to the classic works of Chladni, Izarn, and the *Catalogue* of Biot for further details. Chladni believed that the oldest undoubted meteoric fall of which there was authentic record was that of Crete, which dates back somewhat doubtfully to the year 1478 B.C. Greater interest and certainty are attached to an account given by Pliny in the second book of his *Naturall Historie* (Holland's translation), the Olympian year 78 corresponding to that of 468 B.C. Writing of "stones falling downe from the skie" he says:

Among the Greekes there is much talke of *Anaxagoras Clazomenius*, who by his learning and skill that he had in Astronomie, foretold in the second year of the 78 Olympiad, what time a stone should fall from out of the Sunne: and the same happened accordingly in the day-time, . . . which stone is shewed at this day as bigge as a waine load, carrying a burnt and a dust color: at what time as a comet or blazing starre also burned in those nights. Which if any man beleeve that it was fore-signified, must needs also confesse, that this divinitie or fore-telling of *Anaxagoras* was more miraculous and wonderfull than the thing itselfe: and then farewell the knowledge of Natures workes, and welcome confusion of all, in case we should beleeve that either the Sunne were a stone, or that ever any stone were in it. But, that stones fall oftentimes downe, no man will make any doubt. In the publicke place of Exercise in Abydos, there is one at this day upon the same cause preserved and kept for to be seene, and held in great reverence. It is of but a meane and small quantitie, yet it is that which the self-same *Anaxagoras* (by report) fore-signified that it should fall in the midst of the earth. There is one also at Cassandria. . . . I myselfe have seene another in the territorie of the Vocantians, which was brought thither but a little before.

The earliest authentic meteorite seen to fall and of which portions are still preserved is that of Ensisheim, in Ober-Elsass, Germany. A literal translation of an account of this incident is given below:

On Wednesday, Nov. 7, the night before St. Martins day, in the year of our Lord 1492, a singular miracle happened: for between the hours of eleven and twelve a loud clap of thunder took place, with a long-continued noise, which was heard at a great distance: and a stone fell from the heavens in the Ban of Ensisheim which weighed 260 pounds: and the noise was much louder in other places than here. . . . It did no hurt, except that it made a hole there. It was afterwards transported thence: and a great many fragments were detached from it . . . It was then deposited in the church, with intention of sus-

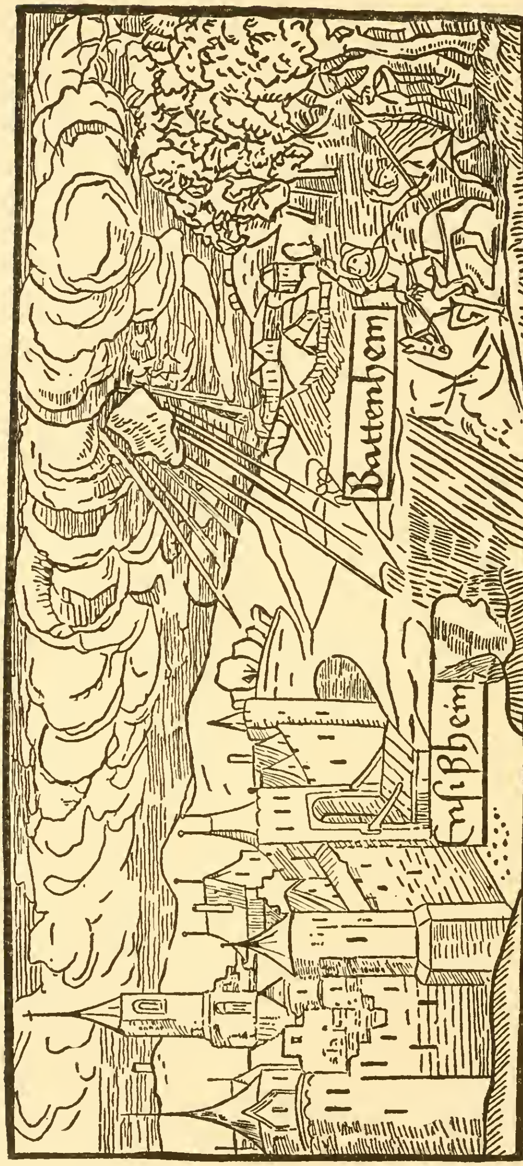


Fig. 1. Fall of meteorite at Ensisheim, Germany, in 1492 (From an old woodcut, originally colored)

pending it as a miracle: and a great many people came hither to see this stone, respecting which there were singular discourses. But the learned said they did not know what it was, for it was something supernatural that so large a stone should fall from the atmosphere: but that it was a miracle of God: because, before that time, nothing of the kind has ever been heard of, seen, or described. When this stone was found, it had entered the earth to a depth equal to the height of a man. What everybody asserted was, that it had been the will of God that it should be found. And the noise of it was heard at Lucerne, at Villing, and many other places, so loud that it was thought the houses were all overturned. . . . The people talked a great deal of this stone which was suspended in the choir, where it still is, and many come to see it. And when King Maximilian was here, the Monday after Saint Catherines day of the same year, his Excellency caused the stone which had fallen to be carried to the castle; and after conversing a long time with his Lords, he said: The people of Ensisheim should take it; and he gave orders that it should be suspended in the church and that no person should be permitted to take any part of it.[1] His Excellency however took two fragments: one of which he kept and the other he gave to Duke Sigismund of Austria.[2]

Equally worthy of reproduction in its entirety is an account of a fall said to have taken place in Berkshire, England, in 1628. Unfortunately none of the material of this fall is known to have been preserved. The account, as given by Lockyer in his *Meteoritic Hypothesis*, is stated to be from "a very rare tract, a copy of which is in the British Museum" and which bears the following title:

Looke Vp and See Wonders: a miraculous Apparition in the Ayre, lately seen in Barke-shire at Bawlkin Greene, neere Hatford, 9th April, 1620. (Imprinted at London for Roger Mitchell.)

[1] Nevertheless eager collectors have been successful in scattering fragments of the stone widely. Wülfing lists sixty collections in various parts of the world containing each from one to 400 grams of it, 54,800 grams still remaining at Ensisheim; in the National collections at Washington the fall is represented by two pieces weighing respectively 200 and 250 grams. The original weight of the entire mass is given as 127,000 grams.

[2] The condition of the popular mind regarding such evidence is shown by a letter written by an eyewitness of the fall. This opens as follows: "The cause of my writing to you at this time is by reason of the accident that the Lord sent among us. I have heard of the Lord by the hearing of the ear as the prophet speaketh, but now mine eyes hath seen him. You will marvel that I write thus, for no man hath seen God at any time yet in his works we see him daily, *but now after a more special manner.*" Then after giving a clear account of the whole occurrence, the writer concludes with an exhortation to unbelievers: "Now let the atheist stand amazed at this work of the Lord."

It begins as follows:

So Benummed wee are in our Sences, that albeit God himselfe Holla in our Eares, wee by our Wills are loath to heare him. His dreadfull Pursiuants of *Thunder* and *Lightning* terrifie vs so long as they have vs in their fingers, but beeing off, wee dance and sing in the midst of our Follies.

Then, continuing, the author tells how

the foure great quarter-masters of the World (*the foure Elements*) . . . have bin in ciuill warres one against another . . . As for Fire, it hath denied of late to warme vs, but at vnreasonable rates and extreame hard conditions. But what talke I of this earthy nourishment of *fire*? How have the *Fires* of Heaven (some few years past) gone beyond their bounds, and appeared in the shapes of Comets and Blazing Starres? . . . The *Aire* is the shop of Thunder and Lightning. In that, hath the late bin held a Muster of terrible enemies and threatners of Vengeance, which the great Generall of the Field, who Conducts and Commands all such Armies (*God Almighty*, *I meane*) auert from our Kingdome, and shoote the arrowes of his indignation some other way, upon the bosomes of those that would confound his Gospell . . . Many windowes hath he set open in Heaven, to shewe what Artillery hee has lying there, and many of our Kings have trembled, when they were shewne vnto them. What blazing Starres (euen at Noone-dayes) in those times hung houering in the Aire? How many frightfull Ecclipses both of Sun and Moone? . . . It is not for man to dispute with God, why he has done this so often . . . but, with feare and trembling casting our eyes vp to Heauen, let us now behold him, bending his Fist onely, as lately he did to the terrour and affrightment of all the Inhabitants dwelling within a Towne in the County of Barkshire . . . The name of the Towne is *Hatford*, some eight miles from *Oxford*. Ouer this Towne, vpon Wensday being the ninth of this instant Moneth of *April* 1628, about five of the clocke in the afternoone this miraculous prodigious, and fearefull handyworke of God was presented . . . The weather was warme, and without any great shewe of distemperature, only the skye waxed by degrees a little gloomy, yet not so darkened but that the Sunne still and anon, by the power of the brightnesse, brake through the thicke clouds. . . .

A gentle gale of wind then blowing from betweene the West and Northwest, in an instant was heard, first a hideous rumbling in the *Ayre*, and presently after followed a strange and fearefull peal of Thunder running up and downe these parts of the Countrey, but it strake with the loudest violence, and more furious tearing of the *Ayre*, about a place called *The White Horse Hill*, than in any other.

The whole order of this *thunder* carried a kind of Maiesticall state with it, for it maintayned (to the offrighted Beholders' seeming) the fashion of a fought Battaile.

It beganne thus: First, for an onset, went off one great *Cannon* as it were of *thunder* alone, like a warning peece to the rest that were to follow. Then a little while after was heard a second; and so by degrees a third, vntill the number of 20 were discharged (or there-abouts) in very good order, though in very great terror.

In some little distance of time after this was audibly heard the sound of a Drum beating a Retreate. Amongst all these angry peales shot off from Heauen, this begat a wonderful admiration, that at the end of the report of euery cracke, or *Cannon-thundering*, a hizzing Noyse made way through the *Ayre*, not unlike the flying of *Bullets* from the mouthes of great Ordnance; and by the judgment of all the terror-stricken witnesses they were *Thunder-bolts*. For one of them was seene by many people to fall at a place called Bawlkin Greene, being a mile and a half from Hatford: Which *Thunder-bolt* was by one Mistris *Greene* caused to be digged out of the ground, she being an eye-witnesse, amongst many other, of the manner of the falling.

The form of the *Stone* is three-square, and picked in the end; in colour outwardly blackish, somewhat like Iron: crusted over with that blackness about the thickness of a shilling. Within it is a soft, of a gray colour, mixed with some kind of minerall, shining like small peeces of glasse.

This *Stone* brake in the fal: The whole peece is in weight nineteene pound and a halfe: The greater peece that fell off weigheth five pound, which with other small peeces being put together, make foure and twenty pound and better. . . .

The following condensed account of a fall near Laigle, France, as given by Biot in *Tilloch's Philosophical Magazine*, is also worthy of reprinting in its entirety on account of its importance in settling in the minds of scientific men the question of the ultraterrestrial origin of meteorites.

On Tuesday, April 26, 1802, about one in the afternoon, the weather being serene, there was observed from Caen, Pont-Audemer, and the environs of Alençon, Falaise, and Verneuil, a fiery globe of a very brilliant splendour, which moved in the atmosphere with great rapidity.

Some moments there was heard at Laigle, and in the environs of that city to the extent of more than thirty leagues in every direction, a violent explosion which lasted five or six minutes.

At first there were three or four reports like those of a cannon, followed by a kind of discharge which resembled a firing of musketry; after which there was heard a dreadful rumbling like the beating of a drum. The air was calm and the sky serene, except a few clouds, such as are frequently observed.

The noise proceeded from a small cloud which had a rectangular form, the largest side being in a direction from east to west. It appeared motionless all the time that the phenomenon lasted. But the vapour of which it was composed was projected momentarily from the different sides by the effect of the successive explosions. This cloud was about half a league to the north-north-east of the town of Laigle; it was at a great elevation in the atmosphere, for the inhabitants of two hamlets a league distant from each other saw it at the same time above their heads. In the whole canton over which this cloud hovered, a hissing noise like that of a stone discharged from a sling was heard, and a multitude of mineral masses exactly similar to those distinguished by the name of *meteoric stones* were seen to fall at the same time.

The district in which the stones fell forms an elliptical extent of about two leagues and a half in length and nearly one in breadth, the greatest dimension being in a direction from south-east to north-west, forming a declination of about 22°. This direction which the meteor must have followed is exactly that of the magnetic meridian; which is a remarkable result.

The largest of these stones fell at the south-east extremity of the large axis of the ellipse; the middle-sized ones fell in the centre, and the smallest at the other extremity. It thereby appears that the largest fell first, as might naturally be supposed.

The largest of all those which fell weigh 17½ pounds. The smallest I saw weigh about two gros, which is the thousandth part of the former. The number that fell is certainly *above* two or three thousand.

In this account I have confined myself to a simple relation of facts; I have endeavored to view them as any other person would have done, and I have employed every care to present them with exactness. I leave to the sagacity of philosophers the numerous consequences that may be deduced from them; and I shall consider myself happy if they find that I have succeeded in placing beyond a doubt the most astonishing phenomenon ever observed by man. (See also page 26.)

In Gilbert's *Annalen* for 1806 is an account of a stone shower which gives interesting evidence of an ability to *see things*. Reference is made to a folio volume of woodcuts in the ducal library of Gotha where is recorded a fearful phenomenon and miracle which was seen on March 1, 1564, between Mechel and Brussels. The sky on the occasion was clear at first, but about nine o'clock became fiery, throwing down a reflection upon the earth so that everything became yellowish. In the meantime there appeared in the sky figures of three men in royal robes and with crowns upon their heads, remaining visible for nearly three-fourths of an hour, when they gradually drew near together and in the course of another fifteen minutes disappeared. Then frightful stones fell, large and small, some of which were five or six pounds in weight. So far as known none of this material has found its way into collections.[3]

The first fall of a meteoric stone in America of which there is a satisfactory record was that of Weston in southern Connecticut. This took place on the morning of December 14, 1807, at about half past six. It was observed by a large number of persons and offers a good illustration of the fate that has befallen many a meteoric stone on similar occasions. The account here given is mainly an abstract from the report of Professors Silliman and Kingsley in the *American Journal of Science*.

The meteor was first seen as a globe of fire just passing behind a dark cloud which did not, however, wholly obscure it, the appearance being compared to that of the sun seen through a mist. It came from the north, in a direction nearly perpendicular to the horizon, never making angles with it of more than four or five degrees, and appeared about two-thirds as large as the full moon. When not obscured by clouds it flashed with a vivid light, compared to that of the so-called heat lightning. A conical train of waving paler light, in length some ten or twelve diameters of the body, followed it. The interval of appearance and disappearance was estimated at about

[3] A good historical account of the falls known at the time and the attendant phenomena, together with the gradually developing views on the subject, is given in J. Izarn's *Des pierres tombées du ciel, ou Lithologie atmosphérique*, Paris, 1803. This account, which cannot be reproduced here, closes with the remark: "Finally it is henceforth useless to attempt to either question or verify the fact [of their fall] and it only remains for us to become better acquainted with it in order to find an explanation."

thirty seconds, and it did not vanish instantly but grew fainter and fainter until it finally disappeared about fifteen degrees short of the zenith.

Some thirty or forty seconds after its disappearance there occurred three loud and distinct reports like those of a four-pound cannon close at hand. These were followed by a rapid succession of lesser reports so close together as to produce a continuous rumbling like that of a cannon ball rolling over a floor, or a wagon running rapidly down a long and stony hill. The noise continued about as long as the meteor was rising, and died away apparently in the direction from which it came. The explosions were in all cases followed by a loud whizzing or roaring sound which "excited in some the idea of a tornado; in others of a large cannon shot in rapid motion; and it filled all with astonishment and apprehension of some impending catastrophe." In every instance, immediately after this was heard a sudden and abrupt noise, like that of a ponderous body striking the ground in its fall. After the explosions there fell a number of pieces of stone scattered over a considerable area, the most remote being nine or ten miles from each other in a line closely following the direction of flight. With but one exception the stones were more or less broken. Over 15,000 grams from this fall are preserved in the Mineralogical Museum of Yale University.

The most northerly fall was within the limits of Huntington, where the meteorite struck a granite bowlder with a loud noise and was broken into fragments, the largest of which was not larger than a goose egg. This is stated to have been still warm when picked up half an hour later. A piece weighing some thirty-five pounds, which seemed to result from the second explosion, fell about five miles distant from the first, burying itself to a depth of two feet in the ground. This was unfortunately broken up and scattered. Later a piece stated to weigh seven to ten pounds was found half a mile northwest of this, and one weighing thirteen pounds about the same distance northeast. Two miles southeast of the place where the 35-pound mass fell, a piece thought to have weighed twenty to twenty-five pounds was found but this also was broken up. The largest piece of all, weighing 200 pounds, fell some two miles further south. It is greatly to be regretted that so large a portion of this interesting and well authenticated fall should have been scattered and lost, only about forty pounds being now distributed among the various museums.

It was the report of this fall by Silliman and Kingsley that led Thomas Jefferson to make the remark—long-since and repeatedly denied—that it was easier to believe that two Yankee professors would lie than that stones should fall from heaven.

The well-known and now widely distributed Juvinas stone, which fell on June 15, 1821, has been the subject of numerous notices, from among which the following is selected for reproduction.[4]

We, Mayor of the Commune of Juvinas, Canton d'Antraigues, Arrondissement de Privas, département de l'Ardèche, report, that on the 15th of this present June, warned by a frightful noise, which was heard in our commune, and those which surround it, about three o'clock in the afternoon, we apprehended that some great and extraordinary event was about to effect a general destruction in nature, which obliged us successively to adopt regulations to satisfy us that no one in our jurisdiction had been the victim of the phenomenon which at first appeared to be inexplicable.

At length, after some days had elapsed, we were informed that a meteor, of which history furnishes no similar account, had burst upon the mountain de l'Oulétte, in the hamlet of Cros du Libonez, forming a part of our commune; and, according to Delmas, who is seventy years of age, its appearance was preceded and announced by two strong explosions, occurring nearly together, resembling the discharges of two large cannons, and followed by a frightful noise, that continued for more than twenty minutes, which spread alarm and consternation amongst the inhabitants, who believed they should be immediately swallowed up by some abyss ready to open under their feet; the flocks fled, and the goats and sheep collected in groups. At the same time

[4] *Thomson's Annals of Philosophy*, Vol. 20, 1822, pp. 73-74.

a black mass was seen coming from behind the mountain de l'Oulétte, describing, as it descended in the air, a quarter of a circle, and sinking into the hollow of the valley of Libonez.

This remarkable circumstance was scarcely perceived by any but children, who, less alarmed than more competent persons would have been, followed the direction, and have since pointed out the exact spot where this mass was swallowed up. Delmas adds that he heard in the air a confusion of voices, which he thought were, at least, five hundred devils, and whom he considers as the agents that transported this alarming phenomenon; at the moment he said to Claude Vaisse, one of his neighbors (who, like himself, was in the fields), "Do you hear; do you understand the language of all these people?" This person replied frankly, "I do not comprehend them"; but they were both persuaded that this mass was carried by infernal spirits. Delmas, for the latter reason, said to Vaisse, "We have only time for one act of contrition," cast his eyes on the ground, bowed his head, and tranquilly waited for death. Such was the consternation of all the witnesses of this terrible event that, according to their confession, they fancied they already saw the mountains rolling and heaped upon them.

The alarm was such, that it was not till the 23d of the month that they resolved to dig out this prodigy, of which they knew neither the form, the nature, or the substance. They deliberated for a long time, whether they should go armed to undertake this operation which appeared so dangerous; but Claude Serre (sexton) justly observed, that if it was the devil, neither powder or arms would prevail against him, that holy water would be more effectual, and that he would undertake to make the evil spirit fly; after which they set themselves to work, and after having sunk nearly six feet, they found the aerolite, weighing rather more than 202 pounds (English). It was covered with a black bituminous varnish, and some parts of it had a sulphurous smell. It was requisite to break it to get it out; there still remains a mass weighing about 100 pounds.

All the facts above stated are proved by all the inhabitants of the hamlet of Libonez; and especially Delmas, sen. and jun.; James and Claude Serre, Peter Charayre, John Chaudouard, Anthony Dumas and his child; and also Mary Ann Vidal, a young girl of about fourteen years of age; the two latter, who were less frightened, followed the direction of the stone, and actually found the place where it was buried. Concerning all which we have drawn up the present *proces-verbal* as a continuation of the history of these phenomena, a copy of which we shall send to M. the Prefect. (Drawn up and agreed upon at our house, the 25th of June, 1821.)

We, the Mayor of Juvinas, certify, that three days after, on the 26th of June, on visiting the place where this stone fell, another was

Meteoric Stone, New Concord, Muskingum County, and Guernsey County, Ohio

About fifteen minutes before 1 p.m., on May 1, 1860, the people of southeastern Ohio and northwestern Virginia were startled by a loud noise likened to the firing of heavy cannons, or to the explosion of a steamboat boiler. In all, twenty-three distinct detonations were heard followed by a series of rattling reverberations. The area over which these sounds were heard was not less than 150 miles in diameter. The cause of these sounds was the falling of a large number of stony meteorites upon an area about 10 miles long by 3 miles wide. The largest weighed 103 pounds. It struck the earth at the foot of a large tree and penetrated a hard clay 2 feet 10 inches. The entire weight of the stones recovered was about 770 pounds, distributed among thirty specimens

found at a short distance from it, which weighed about two pounds and a quarter; it was covered with a similar varnish, and entirely distinct from the first. (A true copy delivered by us, the Mayor of the Commune of Juvinas, the 3d of July, 1821.)

A mass of this stone weighing over forty-two kilograms is preserved in the Natural History Museum of Paris. The remainder in fragments of one gram and upward is scattered through the collections of over sixty museums and private collectors.

Continuing in chronological order, we have next to mention one of the most noted of American falls—that of Guernsey County, or New Concord, Ohio, in 1860. This was described by an eyewitness as follows:

On Tuesday, the first of May, at twenty-eight minutes past twelve o'clock, the people of that vicinity were almost panic-stricken by a strange and terrible report in the heavens, which shook the houses for many miles distant. The first report was immediately overhead, and after an interval of a few seconds was followed by similar reports with such increasing rapidity that after the number of twenty-two were counted they were no longer distinct, but became continuous, and died away like the roaring of distant thunder, the course of the reports being from the meridian to the southeast. In one instance three men working in a field, their self-possession being measurably restored from the shock of the more terrible report from above, had their attention attracted by a buzzing noise overhead, and soon observed a large body descending strike the earth at a distance of about one hundred yards. Repairing thither they found a newly-made hole in the ground, from which they extracted an irregular quadrangular stone weighing fifty-one pounds. This stone had buried itself two feet beneath the surface, and when obtained was quite warm. (See Plate 3.)

Accounts by other observers differ somewhat, but are not seriously contradictory. From all it would appear that the explosion was heard over an area not less than 150 miles in diameter; that the central point from which the sound emanated was near the southern part of Noble County, Ohio, and that the course was over the eastern end of Washington County, then across the interior of Noble County over the southwestern corner of Guernsey and the northeastern corner of Muskingum, with a direction of about forty-two degrees west of north, the stones reaching the ground at an angle of about sixty degrees. Over thirty pieces were found as a result of this fall, scattered over the neighboring farms, and weighing from less than one to 103 pounds, the total weight being estimated at upwards of 770 pounds or 350 kilograms. Of these the largest, the 103-pound mass, is in the museum of Marietta College, Ohio. Examples of this fall are to be found in upwards of fifty collections the world over, in fragments and complete individuals of all sizes up to the largest mentioned.

A shower of meteoric stones which fell near Hessle, near Upsala, Sweden, at 12:20 p.m., January 1, 1869, is worthy of note on account of the perfection of the record, as well as for the large number of individual stones and their somewhat unusual character. The fall is recorded as being accompanied as usual by a noise like heavy thunder, which was followed by a rattling sound as of rapidly driven wagons, ending with a musical, organ-like tone and then a hissing sound. The stones fell in great number and of varying weights, from less than one to 1,000 grams, the total weight being unknown, though 22,895 grams are distributed throughout the various museums and other collections of the world. They were strewn over an area lying thirty degrees east of south to thirty degrees west of north. Although so brittle as to be crumbled between the thumb and finger, but few were broken by force of impact, and one which fell on the ice rebounded without rupture. The most striking and unusual feature, however, was the presence of a coffee-colored carbonaceous matter in powder and in loose masses as large as the hand. This, though largely lost, was found to be made up of granules containing metallic particles which could be extracted with a magnet, leaving a residue consisting of: carbon, 51.6 per cent; hydrogen, 3.8 per cent; oxygen, 15.7 per cent; silica, 16.7 per cent; ferrous oxide, 8.4 per cent;

magnesia, 1.5 per cent; lime, 0.8 per cent; and soda, with traces of lithia, 1.5 per cent. Just what is the meaning of this is not yet apparent.

Beyond question the most remarkable meteoric shower, within the limits of the United States and within historic times, was that of Estherville, Emmet County, Iowa, which took place on May 10, 1879, at 5 p.m. The three largest masses weighed 92½, 170, and 500 pounds respectively, but there were in addition very many smaller pieces weighing from the fraction of an ounce to twenty-eight pounds each. The 92½-pound mass and some 600 of the smaller fragments are in the museum of Yale University.

This meteor was plainly visible in its flight through the air and was described as looking like a ball of fire with a long train of vapor or clouds of fire behind it. Its height above the earth when first seen was estimated at forty miles. The sounds produced by the explosions incidental to its breaking up were referred to as terrible and indescribable, as scaring cattle and terrifying people over an area of many square miles. The first explosion, for there were several, was louder than the loudest artillery; this was followed by lesser sounds, and then by a rumbling noise like the passage of a train of cars over a bridge. Approximately 116 kilograms from this fall are preserved in the British Museum, sixty kilograms in the University of Minnesota, fifty kilograms in the University of Paris, and forty-eight in Yale University. Over seventy of the collections the world over have representative specimens, of less, but varying weights.

Still another shower which is worthy of recall, even at the risk of wearying the reader, was that which took place near Holbrook in Arizona on July 19, 1912. At half past six in the afternoon, while it was still daylight, the meteor was heard passing over Holbrook, traveling almost due east with the usual sounds and leaving a train of thin smoky vapor. It made a very loud noise, lasting for half a minute to one minute, which was likened by witnesses to the rumbling of a rapidly driven farm wagon on a rough road, to escaping steam, to distant or long-continued thunder, or the booming of cannon. One large explosion was quickly followed by several smaller ones in rapid succession and stones began falling "raising many puffs of dust for a mile or more over the dry sand of the desert like those produced by bullets or the first drops of rain in a heavy shower. . . . The meteor was not seen in its flight, as it was too early in the evening for its luminosity to be visible."

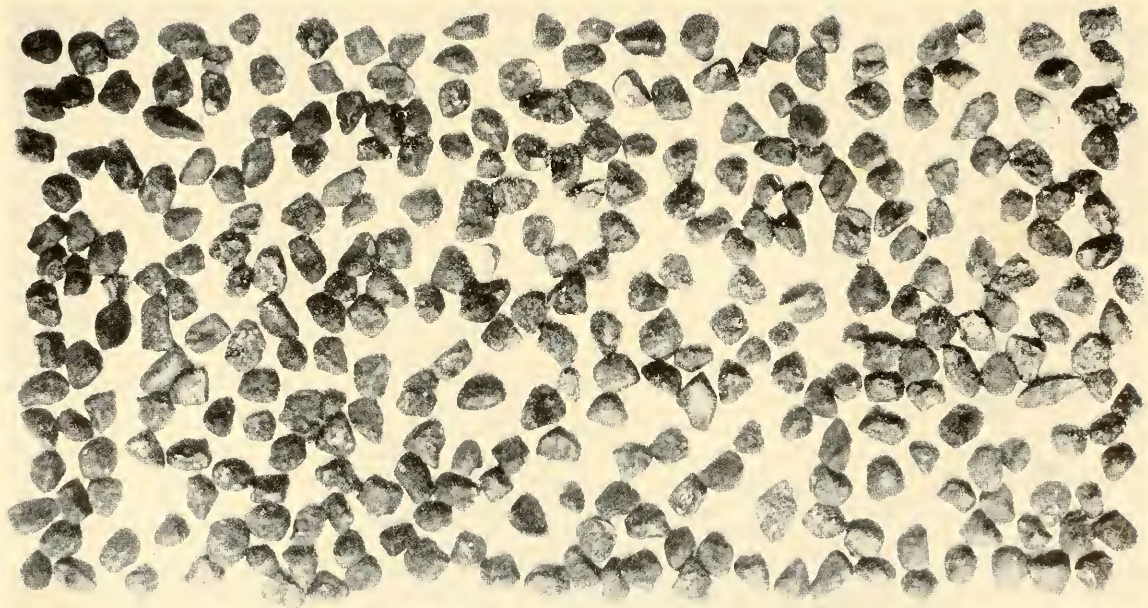
The stone was repeatedly shattered in its passage through the air and the surfaces of the fragments almost immediately fused again, so that each piece as found is covered with the black crust so characteristic of meteoric stones. The really extraordinary feature of the fall is the number of the pieces, of which there were estimated to be some 14,000, varying in size from that of a pea to five or six inches in greatest diameter. The accompanying plate (Plate 4) from the original description[5] shows the actual sizes and shapes of the smaller forms.

The two following falls stand in marked contrast with those just given, each yielding a single individual stone as a record of the event.

The first, that of a stone at Alfianello, Italy, fell on the afternoon of February 16, 1883, and though stated to have been accompanied by a loud detonation, gave no evidence of breaking into fragments. Owing doubtless to the time of day, no light accompanied the fall, but it left behind a trail of vapor comparable with the smoke from a rapidly moving locomotive. The direction of flight was from north-northeast toward the south-southwest. The stone penetrated the soil to the depth of a meter, shaking the ground like an earthquake, and, incidentally, frightened a nearby peasant into a fainting fit. But a single stone fell, which weighed approximately 260

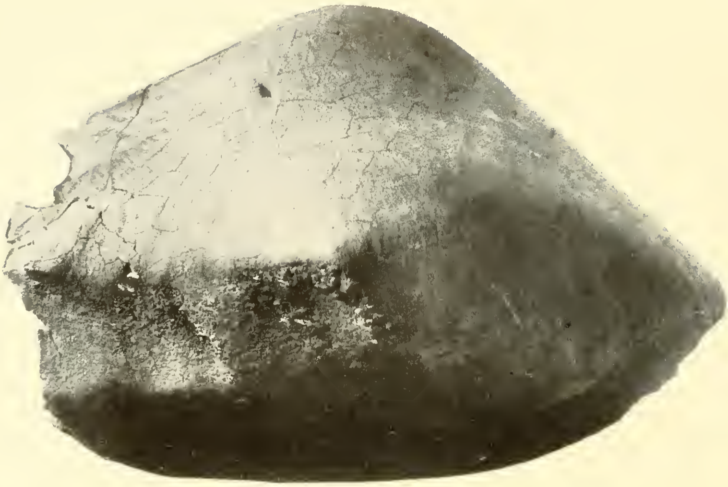
[5] Wm. Foote, *Amer. Jour. Science*, Vol. 34, November, 1912.

PLATE 4



Showing some of the small sizes into which the Holbrook stone was broken

PLATE 5



Meteoric Stone, Allegan, Allegan County, Michigan

This stone, weighing about 70 pounds, fell on the morning of July 10, 1899, on the Thomas Hill, Saugatuck Road, near Allegan, Michigan. The mass came out of the northwest and buried itself about eighteen inches in a loose, sandy soil. The fall was accompanied by a loud report followed by a rumbling and a hissing sound. The stone was dug up a few minutes after the fall and is stated to have been too hot to handle. The characteristic black crust shows well-marked lines of flow and fusion structure, but the mass could not have had a high temperature on striking the ground as the grass roots adhering to it show no signs of charring. The ash-gray groundmass is exceedingly friable and is made up of an agglomerate of particles of olivine, enstatite, chromite, nickel-iron, troilite, and schreibersite. Its structure is chondritic and characterized by the large size and spherical perfection of many of the chondrules kilograms (572 pounds) though it quickly became broken up and the pieces scattered. About one-fifth of the original weight has been preserved, the largest piece, of 12,757 grams, being now in the museum at Berlin.

The Allegan, Michigan, fall, on the morning of July 10, 1899, was also of a single stone. (Plate 5.) This was stated by observers to have come from the northeast, and to have buried itself in the sand to a depth of eighteen inches, striking within ten rods of a man working in the fields.

Attention was first attracted to it by a cannonlike report, followed, as the stone came nearer, by a hissing sound as of an engine blowing off steam. When first seen in the air it had the appearance of a black ball about the size of a man's fist, and as it passed overhead it was described as leaving a "blue streak" behind, but no light. It was dug from the ground but a few minutes after falling and was said to be too hot to hold in the hands, and that the sand was hot around it. Nevertheless, shreds of dead leaves and grass which became closely compacted against its surface on striking, were not charred in the least. It would seem probable that here, as in many other cases, it was expected the stone would be hot, hence it was so reported.

This stone, which weighed approximately seventy-five pounds, was badly shattered in falling. The main mass is among the collections of the National Museum.

It will be noted that all the falls thus far described yielded stones or stony irons. Of all the known *iron* meteorites, but seventeen were seen to fall, and of these only that of Mazapil, Mexico, need be given in detail. The account is that of one Eulogio Mijares, a ranchman living at Mazapil. This fall is of special interest, having taken place during one of the periodic meteor displays.

It was about 9 o'clock in the evening (November 27, 1885) when I went to the corral to feed certain horses, when suddenly I heard a loud sizzing noise, exactly as though something red-hot was being plunged into cold water, and almost instantly there followed a loud thud. At once the corral was covered with a phosphorescent light and suspended in the air were small luminous sparks as though from a rocket. I had not recovered from my surprise when I saw this luminous air disappear and there remained on the ground only such a light as is made when a match is rubbed. A number of people from the neighboring houses came running toward me and they assisted me to quiet the horses which had become very much excited. We all asked each other what could be the matter, and we were afraid to walk in the corral for fear of getting burned. When in a few moments we had recovered from our surprise we saw the phosphorescent light disappear, little by little, and when we had brought the lights to look for the cause, we found a hole in the ground and in it a ball of fire (*una bola de lumbre*). We retired to a distance, fearing it would explode and harm us. Looking up to the sky we saw from time to time exhalations or stars, which soon went out, but without noise. We returned after a little and found in the hole a hot stone, which we could barely handle, and which on the next day looked like a piece of iron; all night it rained stars, but we saw none fall to the ground as they seemed to be extinguished while still very high up.

In view of what has just been said concerning the temperature of the Allegan meteorite, attention should be called to the fact that this was an iron. The reason for this remark will appear later.

The most remarkable of meteoric *finds* within the limits of the United States, or indeed in the world,[6] is that of Canyon Diablo, in Arizona. At and about a point between Winslow and Flagstaff, in Yavapai County, and south of the Santa Fé railroad, several thousand pieces of metallic (meteoric) iron, in weight from a gram to 1,000 pounds, have been found, for the most part scattered over an oval area some 3½ by 4½ miles, though one of the largest masses was found eight miles to the eastward. The total weight of all the material will never be accurately known, but it must lie somewhere between fifteen and twenty tons. Nothing, even by tradition, is known regarding the date of fall. So large a quantity of meteoric material scattered over the plain would in itself excite

[6] Unless certain recent newspaper accounts of an occurrence in Siberia should prove correct.

PLATE 6

Meteoric Iron. Fell at Mazapil, Mexico, Nov. 27, 1885. Weight about 4 kilograms or 8.8 lbs. Note the beautiful sculpturing or piezoglyphs. For description of fall see p. 21

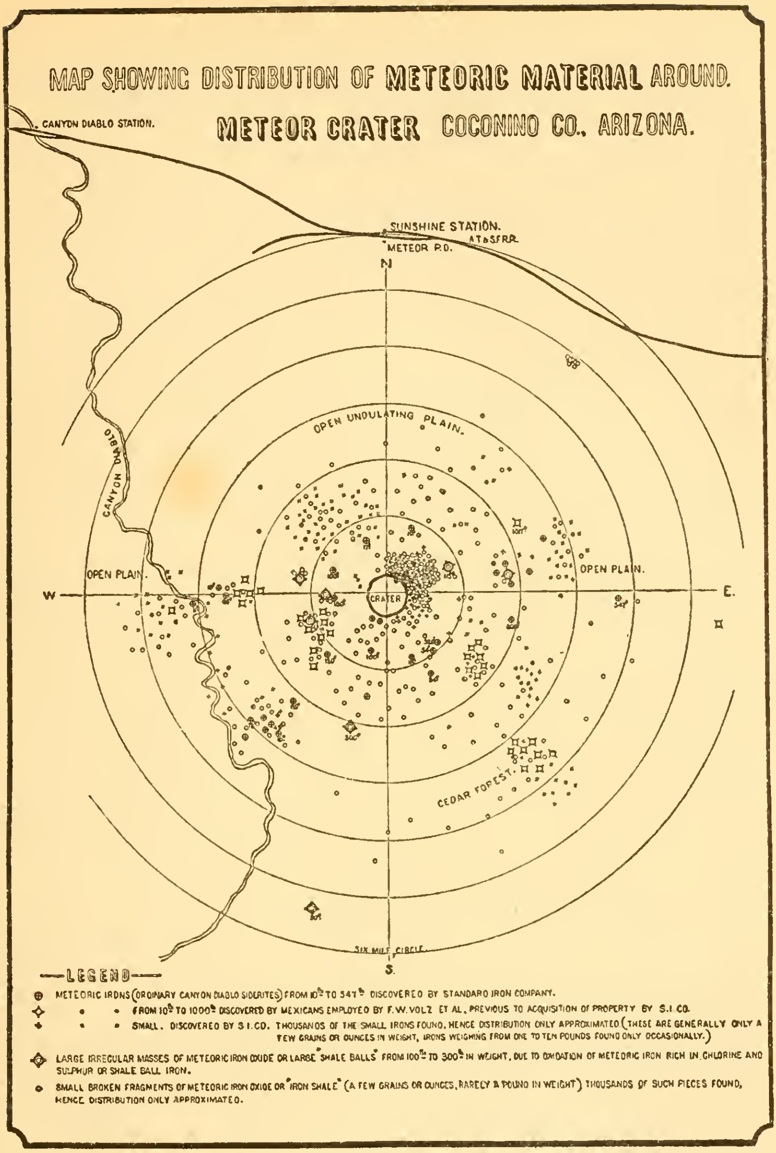


Fig. 2. Area of distribution of Canyon Diablo Meteorite.
(After D. M. Barringer)

interest and curiosity and taken in connection with the existence, close at hand, of an immense crater-like depression, early gave rise to the theory that the crater itself (Plate 7) was due to the impact of an enormous meteorite. This occurrence has often been described[7] but is of sufficient interest to merit additional notice here. The region is that of an elevated, nearly level, sandy plain the floor of which is composed in the main of a buff-colored arenaceous limestone which is capped here and there by residual patches of red sandstone and underlain by a highly siliceous, friable sandstone. The crater-form depression is some 4,000 feet across and 600 feet deep, the original depth having been greatly lessened by *débris* blown in from the surrounding plain. The crater rim is composed of the upturned, crushed, broken, and bent beds of sand and limestone overlain by large blocks, sometimes thousands of tons in weight, of the same material thrown out from the crater itself. In addition are enormous quantities of finely pulverized siliceous sand which has plainly been derived from the sandstone by the shock of an explosion or the impact of some descending body. There are also, intermingled with this, occasional blocks of siliceous pumice which apparently owe their origin to the fusion of the same sandstone. So convincing are these facts that extensive drilling and tunneling have been undertaken in the hope of finding a buried monster meteorite.

Though the illustrations given can leave no present doubt as to the ultraterrestrial origin of meteorites, it is but natural that there should at first have been much skepticism both in the popular and scientific mind regarding the possible fall of stones from empty space. So great was this skepticism that, as stated by E. F. F. Chladni, of Vienna, in his *Feuer-Meteore* published in 1819, the examples preserved in the public museums were hidden or

[7] Meteor Crater in Northern Central Arizona, by D. M. Barringer, and others by the same author. Also The Meteor Crater of Cañon Diablo, etc., by Geo. P. Merrill, *Smithsonian Misc. Coll. Q. Issue*, Vol. 50, Pt. 4, 1908.

PLATE 7

Meteor Crater, Arizona. From a photograph. (Courtesy of the U. S. Army Air Service)

PLATE 7

Meteor Crater, Arizona. From a photograph. (Courtesy of the U. S. Army Air Service)

discarded, the custodians fearing to make a laughing-stock of themselves through acquiescing in the possibility of their extraterrestrial origin. As long since noted by Izarn, it was those trained in power of observation and able to realize the improbabilities of such an occurrence that were slowest to accept the idea of an ultraterrestrial source. The Swiss geologist, J. André de Luc, is quoted as saying that though he should see one fall he would not believe it.[8]

The fall in 1492 of the meteoric stone at Ensisheim, an account of which is given on page 7, would seemingly have been sufficiently convincing, but even as late as 1772, a committee, one of whom was the celebrated chemist, Lavoisier, presented to the French Academy a report on the examination of a stone seen to fall at Lucé four years previously. In this they took the ground that the supposed sky stone was but an ordinary terrestrial rock that had been struck by lightning.

As early as 1794, Chladni, referred to on the previous page, had called the attention of the scientific world to the fact that several masses of iron had in all probability come to our earth from outer space. He referred especially to the now well-known Pallas stony-iron, which was found by a Cossack in 1749, among schistose rock, and in the highest part of a lofty mountain near Krasnojarsk in Siberia. It was regarded by the native Tartars as a holy thing fallen from heaven, which fact would certainly seem to indicate that it was seen to fall. Chladni argued that this iron could have been formed only under the influence of fire. The absence in the vicinity of scoriae, the ductility of the iron, the hard and pitted surfaces, and the regular distribution of the included olivine, to his mind precluded the idea that it could have been formed where found, or by man, electricity, or an accidental conflagration. Hence, he inferred that it had been projected from a distance, and, as there were no volcanoes

[8] "Ich habe es gesehen, ich glaube es aber doch nicht."

known to eject iron, and as, moreover, there were no volcanoes in the vicinity, he was compelled to look for an extraneous source, and to regard it as actually having fallen from the sky. Incidentally, he argued, the flight of such a body through the atmosphere would give rise to all the phenomena of the fireball or shooting star.

It was, as has been remarked, as if to direct attention to Chladni's work that there occurred during this same year an observed shower of meteoric stones near Siena, Italy. In December of the following year, also, a 56-pound stone fell out of a clear sky almost at the feet of a laborer near Wold Cottage in Yorkshire, England, and again in 1798, under similar conditions, many stones fell at Krakhut, near Benares, in India.

Notwithstanding all these and numerous other recorded occurrences, the scientific minds of the day remained unconvinced, or only partially convinced. Fortunately there occurred in broad daylight about this time (April 26, 1803) a shower of upward of 3,000 stones in the neighborhood of Laigle, France, already mentioned. The circumstances of this fall were thoroughly investigated under the auspices of the French Academy of Sciences (see page 11). The report, covering over forty quarto pages, was of so conclusive a nature as to forever set aside all doubts as to their ultraterrestrial nature and probable source.[9]

[9] Nevertheless there remained doubters. An amusing illustration of the varying opinions on the subject, as well as of the condition of chemistry and power of observation at the time, is given by a writer in *Tilloch's Magazine* (Vol. 46, 1815). "Why," he writes, "do men of science persist in saying that meteoric stones fall from the heavens, as if planets could contain within their bodies a force of projection superior to their force of gravity, and capable of pushing their matter beyond the limits of their attraction, or as if masses so enormous could be formed in the air; where, besides, there exists no base of bodies as in the azote, without an extrication of air, felt over the whole globe, being the effect of it.... The phenomenon always takes place in open grounds and where without finding much resistance the stone may sink into the ground; therefore they do not fall, but are formed of the substance of the soil, which the lightning puts in a state of fusion. If this substance be pure silex the stone forms rock crystal rounded like flint. If it be a mixed soil, the flux is also mixed and some of its oxides may, by the force of the fire be reduced, nay it is even compounded into metal."

Portrait of E. F. F. Chladni. From an engraving in Flight's *A Chapter in the History of Meteorites*

PLATE 9

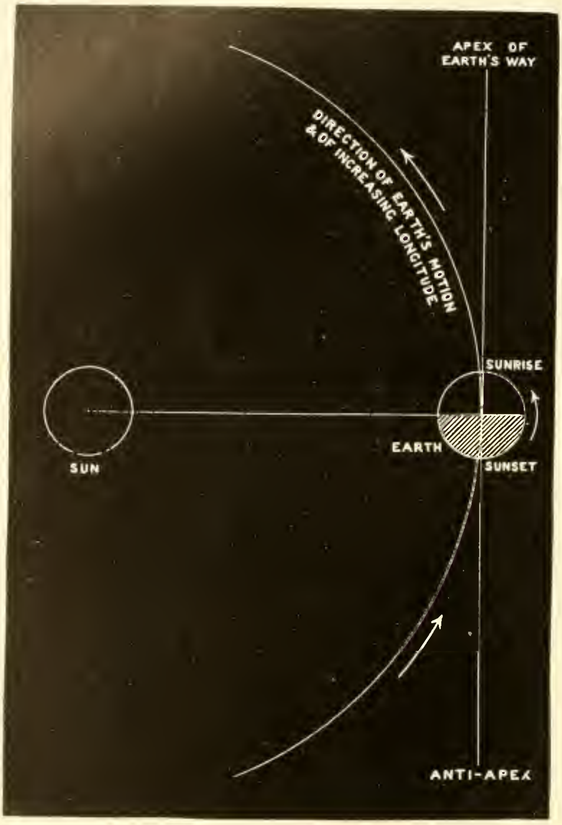


Diagram of earth and sun

CHAPTER II

PHENOMENA INCIDENTAL TO FALL

In the accounts given in the previous chapter it will be noted that much stress is laid upon the phenomena of sound and light attendant upon the fall of a meteorite. That these phenomena are due wholly or in part to the rapid passage of the bodies through the air and the resistance encountered would seem unquestioned. It will be well, then, to give this phase of the subject a share of our attention.

The astronomer Newton calculated the speed of the fire-balls which passed over the Ohio and Mississippi valleys in August, 1860, as thirty to thirty-five miles per second, and it is stated that the stone of Stannern, Moravia, which fell in 1808, came into the earth's atmosphere with a velocity of forty-five miles per second.

That there may be actually a considerable variation in these velocities will be readily apparent when consideration is given to the direction of the flight with reference to that of the earth, as shown in the accompanying diagram. (Plate 9.) If a body is following the earth in its course about the sun the apparent speed will be but differential. Thus a meteorite with a velocity of twenty-five miles per second overtaking the earth traveling at the rate of nineteen miles per second, would enter our atmosphere with an initial speed of but six miles per second. In the case of a meteorite pursuing a retrograde course, conditions would be greatly exaggerated. With the same velocity it would meet the earth traveling in the opposite direction, and hence would enter our atmosphere with an initial velocity of forty-four miles per second. This is, however, far above the speed with which the meteor actually reaches the earth, atmospheric pressure so far retarding it that it may fall with little if any speed higher than that imparted to it by gravity. In this connection the following table by G. von Niessel, showing the height above the earth at which certain meteorites have lost their initial velocity, is of interest:

Von Niessel's Table

	Miles
Homestead	2.30
Krähenberg	5.09
Mocs	5.21
Weston	6.89
Knyahinya	7.38
Braunau	9.19
Orgueil	14.28
Pultusk	25.76
Hraschina	29.00

From whatever direction the meteorite comes, it is meteoric *stone* which has come under the writer's observation is that of Knyahinya, Hungary, as described by Haidinger. In this instance a 660-pound stone (Figure 3), views once held concerning the possible identity of the shooting stars and meteorites.

The astronomer Herschel calculated the velocity of the Yorkshire, England, meteorite at the time it reached the ground as but 412 feet a second. The Guernsey County, Ohio, stone was estimated to have reached the earth while traveling at a speed of three or four miles a second; that of Weston, Connecticut, while at a height of some eighteen miles, was estimated by Professor Bowditch to have a velocity of three miles a second. The evidence of speed afforded by the impact of actual falls is extremely contradictory. Obviously a stone falling from a great height would, if gravity alone were considered, reach the surface with the greatest force of impact. Nordenskiöld states

View of a portion of the moon's surface. Compare with view of Meteor Crater, Plate 7

that in the case of the Hessle fall, stones so friable as to be readily broken if simply thrown against a hard surface, were not broken or even scarred on striking the frozen ground. Stones weighing several pounds which struck on ice a few inches in thickness rebounded without breaking the ice or being themselves broken. The 70-pound stone that fell at Allegan, Michigan, in 1899, penetrated the sandy soil to a depth of about eighteen inches and was itself considerably shattered. Like that of Hessle, this was an unusually friable stone. It is evident that its speed did not equal that of a projectile from an old-time piece of heavy ordnance. The 260-pound stone that fell at Ensisheim, Germany, in 1492, is reported to have buried itself to a depth of five feet. The greatest depth of penetration of a meteoric *stone* which has come under the writer's observation is that of Knyahinya, Hungary, as described by Haidinger. In this instance a 660-pound stone (Figure 3), striking the ground at an angle of some twenty-seven degrees from the vertical, penetrated to a depth of eleven feet. The hole was nearly circular in outline and fragments from the interior were thrown back and scattered to a distance of some 180 feet (*dreizig Klafter*). The stone was found broken in three pieces and the earth beneath it compacted to a stony hardness. The 71-pound mass of the Hraschina *iron* is stated to have buried itself to a depth of eighteen feet. On the other hand, still heavier

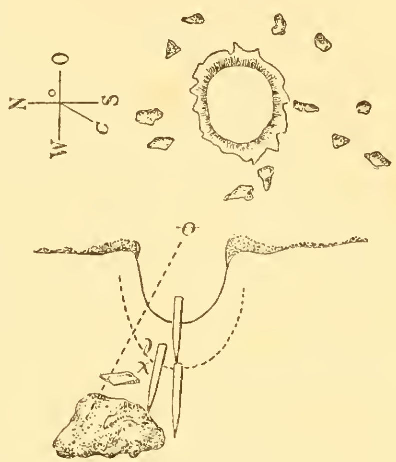


FIG. 3. Diagram of fall of meteorite at Knyahinya, Hungary

masses have been found under such conditions as to lead one to infer that they scarcely buried themselves.

Peary's giant Cape York iron, weighing 37½ tons, was found only partially covered, but as it lay on a bed of gneissic bowlders, this is not strange. It should be remarked, however, that an examination of the iron reveals no such abrasions of the surface as might be expected had it fallen with a speed of whole miles per second, nor, indeed, any abrasions whatever that can be ascribed to such a cause. It is, of course, possible that this fall took place when the ground was deeply covered with ice and snow, and its speed was thus checked before coming in contact with the stony matter.

The Willamette, Oregon, iron, weighing 15.6 tons, seemingly without question lay as it originally fell, and in a region of no appreciable erosion—rather one of organic deposition—for it was found lying in a primeval forest; yet the mass was scarcely buried, a small projecting portion leading to its discovery.

The Bacubirito, Mexico, iron, weighing, at a rough estimate, twenty tons, lay in a soft soil but little below the general surface of the field around it.

Although so seemingly ineffective, it is nevertheless permissible, without being sensational, to consider for a moment what might be the result of meteoric bombardment were not our earth protected by its armorplate of atmosphere. Probably the surface of the moon, spotted over by deep pits, offers the best illustration of the possible consequences.

The hissing sounds so frequently reported in meteorite falls may seemingly be ascribed to speed alone, as in the case of a rifle ball or other high-power projectile; the thunderlike sounds to the same cause as those of ordinary thunder—the collapsing of an atmospheric vacuum, as caused by lightning. The crackling and crashing sounds are due largely to the breaking up of the meteorite during its descent, a feature itself due to the pressure of the atmosphere and to the expansion of the exterior shell through heat produced by the same cause. The astronomer Herschel has stated that at the height of twelve miles a velocity of twenty-seven miles per second would produce a pressure of a little over 10,000 pounds per square inch. While an iron meteorite might withstand this, a stone would almost certainly be crushed. This would account for so many stony meteorites coming to us in the form of showers of fragments.

The astronomer Young has stated that the quantity of heat evolved in bringing to rest a body which has a velocity of forty-two kilometers or twenty-six miles a second is vastly more than sufficient to fuse it, even were it composed of the most refractory material. The effect, indeed, is the same as though the meteor was immersed in the flame of a blowpipe having a temperature of many thousands of degrees. With a moving body having a velocity of about 1,500 meters per second, the temperature would be raised to about that of redness. With a speed of twenty or thirty miles per second, the meteor would be acted upon as if immersed in a temperature of several thousand degrees, and the liveliest incandescence would result, the meteor becoming fused and catching fire on the immediate surface and being perhaps almost entirely consumed. H. E. Wimperis, indeed, has calculated that, owing to this cause, no iron less than ten pounds in weight on entering the atmosphere would survive. That the meteors of different showers exhibit these described features with different degrees of intensity arises, according to the astronomer Chambers, from the fact that their apparent speed depends in a great measure upon the angle with which they meet the earth, as already noted.

Thus the meteors of November 13 (Leonids) are moving in a direction opposite to the earth; hence their veolcity is very great, being about forty-four miles per second. But the meteors of November 27 (Andromedes) are moving in nearly the same direction as the earth, and hence have to overtake us, so that they apparently move very slowly, their speed being only eleven miles per second. The Leonids above referred to, together with the Perseids of August 10 and the Orionids of October 18–20, are good examples of the swift-moving meteors, and they are almost invariably accompanied by phosphorescent streaks. The slow meteors, of which the Andromedes are a type, throw off trains of yellowish sparks.[1]

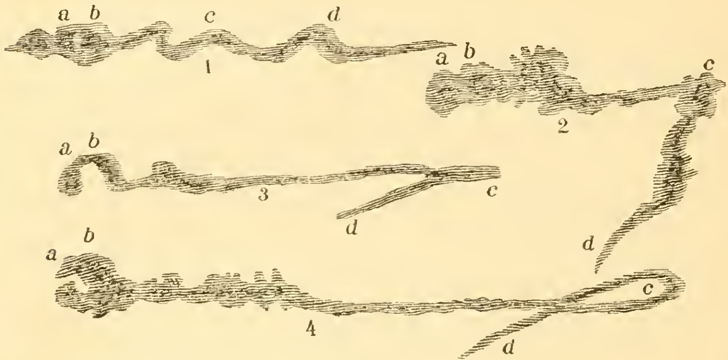


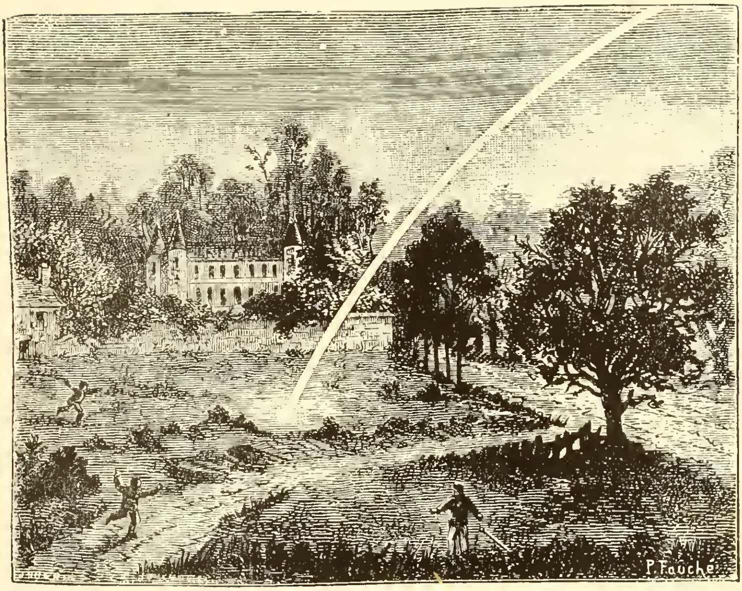
FIG. 4. The afterglow of meteorites

The pressure of the air in any case is such that the fused and burning materials are immediately stripped off the outer exposed portions, forming the trail of light, so conspicuous a feature of the early part of the phenomenon. This, of course, does not apply to the so-called "afterglow" (Figure 4) which sometimes remains in the air for several minutes after the meteorite has passed and which is commonly believed to be due to phosphorescent nitrogen and perhaps other gases formed by the heat of the passing body.[2] Only on the rear, if at all, does the fused material accumulate to an appreciable thickness. As the meteorite

[1] Handbook of Descriptive and Practical Astronomy: Sun, Planets, Comets, 4th ed. Vol. 1, p. 635.

[2] "The motion of the meteor through the atmosphere produces an exceedingly high temperature and may bring about chemical or physical changes in the composition of the atmosphere in the track of the meteor, which on reverting to its original state gives out a phosphorescent glow, or the surrounding air may be highly ionized by the vaporizing meteor so that electrical discharges take place great enough to produce an afterglow like that following the electrodeless discharge." C. C. Trowbridge, *Proc. Nation. Acad. Sci.*, Vol. 10, 1924, p. 38.

PLATE 11



Fall of a meteorite at Montpreis, in Styria, on July 31, 1859. (From *L'Astronomie*, Vol. 2, 1883)

approaches the earth the speed is gradually checked, and by the time it is reduced to two miles a second, the heat generated is no longer sufficient for fusion, the remaining thin coating of molten material quickly congeals as a black crust, and the stone drops to the earth no longer luminous and doubtfully even hot. The word *doubtfully* is used here intentionally, for reports on this phase of the subject are very contradictory. Before giving the evidence pro and con, the reader is, however, asked to consider the probabilities.

As is well known, the temperatures at comparatively short distances above the earth are very low; even at the slight altitudes reached by flying machines it is "freezing cold," and astronomers and physicists tell us that the cold of space is that of "absolute zero." Now the meteor has been wandering through this space for untold years and but for absorption of heat from the sun on its way to earth must in time acquire a like temperature. The problem of determining the probable temperature of falling bodies in space is extremely complex and cannot be touched upon here. Reference may again be made to the calculations of Prof. H. E. Wimperis, who, from a study of the conditions of flight of a meteorite compared with artillery shells, reached the conclusion that an iron meteorite of ten to twenty pounds in weight would have at the center, on reaching the earth, a temperature not far from that of liquid air (−140° C. or −220° F.). Prof. A. T. Jones, in a recent reconsideration of the problem, arrived at the conclusion that when a meteorite falls during the daytime, its temperature is probably not far from 0° C. when it enters the atmosphere of the earth. Widely variant as these estimates seem, they are sufficient to show that whatever apparent heat the stone or iron possesses at the time of its fall must have been acquired wholly through atmospheric pressure during the few last brief seconds of its flight. But, as has been stated, the heated surface of the flying body is stripped off almost as fast as formed, and never, so far as shown, penetrates to any appreciable depth. Hence, it seemingly follows that in the case of poor heat-conducting substances like meteoric stones, the heat at the time of their reaching the ground must be practically negligible, differing little if any from that possessed at the time they entered the atmosphere, let this be 0° C. or −140° C., as the case may be.

Actual testimony, in print or otherwise, is quite contradictory, and allowance must be made for the fallibility of the human mind as so frequently exemplified in the courts, particularly in the case of unusual or startling phenomena, and for a natural predilection on the part of an individual to report an object as in the condition in which he has been led to expect to find it.

Poggendorff, in his *Annalen* for 1838, records the setting of fires by meteorites in 1761 at Burgoyne, France, Bury St. Edmunds, and other localities. According to Haidinger, some stones which fell in Styria in 1859 continued in a state of incandescence for from five to eight seconds, and for a quarter of an hour were too hot to be handled without burning. Beinert, in his account of the Braunau iron (1847), states that for six hours it remained too hot to be handled, as did also that of Mazapil, Mexico (1887), referred to on page 21. In an account of the fall of an iron meteorite in Mogul, India, it is stated that the earth for a distance of ten to twelve yards about the spot was "burnt to such a degree that not the least trace of verdure or blade of grass remained," and that on attempting to dig it up "the heat was so violent that one might have supposed it to have been from a furnace, but became cold after some time." Unfortunately there are indications of exaggeration in these accounts such as to render it unsafe to rely upon them implicitly.[3] The iron which fell at Pitts, Georgia, in 1921, is stated to have

[3] The writer has actually had bowlders from the glacial drift sent him, with similar statements.

been still warm when dug up a few minutes later, but not red-hot, as first reported. Taken in connection with that of the Mazapil fall this account would seem to lend probability to the suggestion elsewhere made that iron meteorites reach the earth while traveling at a higher rate of speed and, being better conductors, become more highly heated than do the stones. The Dhurmsala stone of 1860 is stated to have been intensely cold when picked up immediately after falling, frost forming on its surface. The stone of Alfianello, Italy, is likewise reported by Bombicci to have been extremely cold internally,[4] as was also that which fell at Olivenza, Spain, in 1924. A similar statement regarding the Colby, Wisconsin, stone of 1917 has been made, while the Tilden, Illinois, stone of 1924 is reported as "noticeably cold" when exhumed almost immediately after falling.

The reports of the setting of fires by falling meteorites must be taken therefore with some degree of allowance. The writer considers it more than probable that, were it possible to reinvestigate the early reports, they would be found largely erroneous. In the cases of the Allegan, Holbrook, Winnebago, and Rose City falls, the stones struck on dried grass, which, though pressed closely against the surfaces, was not charred in the least. Indeed, one of the Winnebago stones fell on a stack of dry straw without igniting it.

Naturally the possibility of injury to human beings and other animals by falling meteorites has often been discussed, and several instances are recorded, mostly as having occurred during the sixteenth and seventeenth centuries. It must be confessed, however, that owing to the lack of confirmation by writers after the first momentary period of excitement had subsided, there is here also very grave doubt as to the truth of the occurrences; certainly they cannot be accepted as matters of

[4] "Auche Laerolite di Alfianello si trovo' freddissimo nelle superficie di rottura, al momento dello scavo."

fact. Nevertheless, it will be well to recall a few of the reported cases of this nature and to give them whatever credence they seem to deserve.[5]

Bigot de Morogues, in his *Memoirs* published in 1812, quotes the account of two sailors who in 1654 were killed by the fall of a meteorite while standing on the bridge of a vessel sailing between Japan and Sicily. He mentions, too, the fall of an iron at Lessay near Coutenes, France, in 1737, by which animals were killed and many buildings fired.

Some accounts of the fall at Barbotan, France (1790), state that a stone fifteen inches in diameter broke through the roof of a cottage and killed a herdsman and a bullock; subsequent accounts, while confirming the fall through the roof, make no mention of the killing.

Mondegenitus states in his *Life of Marcus Aurelius*, that during the reign of the Emperor Vallatian such a copious shower of stones fell in Constantinople that it killed not only several people but most of the cattle in the fields. Through lack of confirmation this is regarded as altogether improbable.

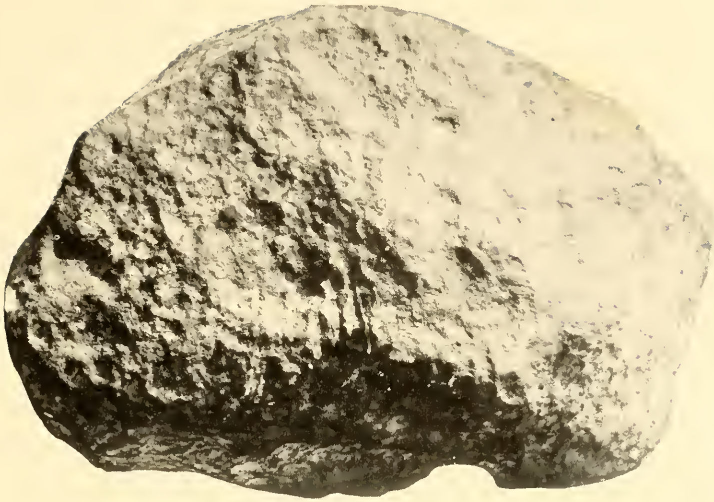
In the *London Philosophical Magazine* of 1811 is an extract from a writer in Futty Ghur (Fettehghur?), India, in which occurs the following:

> I open this letter to let you know of a very odd circumstance which happened a few days ago, viz., a large ball of fire fell from the clouds which burnt five villages, destroyed crops and some men and women. The ball is now still to be seen; it is hard as a stone. This happened near Shahabad, across the Ganges . . . I have heard nothing further about this but a vague report.

Vague indeed it must have been since there is no record of any meteorite having fallen at this locality.

T. F. Phipson, in his book on meteors (p. 85), mentions on the authority of a Carthusian monk the fall of more than a thousand stones at Crema near Milan, Italy, in 1511. The largest of these weighed 120 pounds.

[5] Which is very little.



Meteoric Iron, Casas Grandes, Chihuahua, Mexico

This iron is supposed to be the mass found in 1867 in an old tomb in the ruins of the Montezuma Casas Grandes (large houses), in Chihuahua, Mexico. When found it was "carefully and curiously wrapped with a kind of coarse linen, similar to that with which the Egyptians inclose or wrap their mummies." "Twenty-six yoke of sturdy oxen were mustered and as many or more strong log-chains, and, with this force and tackle the monster meteorite was hauled from there to the modern town of Casas Grandes." Some doubt has been cast upon the identity of the iron here shown and that above described by the somewhat conflicting statements regarding the weight and size. The iron weighed before cutting 3,407 pounds. It was cut in order to give a flat surface for etching, to show its crystalline structure which is octahedral. Nothing is known concerning the date of its fall

Birds and sheep were reported killed by this fall and also one human being, a Franciscan friar.[6]

Even as late as 1838 we have an account of the fall of an immense quantity of stones in the Province of Ceará in Brazil, in which the roofs of dwellings were penetrated and many animals killed, although no human life was lost. Here again it should be noted that subsequent accounts by Derby and others make no reference to such an incident nor is there any record of such a fall. It is a fair assumption that every one of these recorded cases simply illustrates the tendency to exaggerate so characteristic of the human species during periods of momentary excitement. That the fall of a large meteorite *might* inflict serious injury is unquestioned. The possibilities of such an occurrence are, however, so slight as to be almost negligible.

That many individuals ascribe to meteorites the shower of stones which destroyed the enemies of Joshua at Beth-horon is well known, but needs no comment.

It is but natural that in the early days of superstition and occasional idolatry the phenomena of a falling meteorite should have been considered due to supernatural causes, and the body itself, if found, regarded with more than usual fear or veneration as the case might be. Out of the many instances of this kind that might be mentioned, but few are worthy of repetition here.[7] It is stated that a stone which fell in ancient Phrygia, in Asia Minor, about 200 B.C., was worshiped by the Phrygians and Phœnicians as Cybele, the mother of the gods. Another, of which the history goes back far beyond the seventh century A.D., is the sacred *Black Stone* of the Mahommedans, still preserved at Mecca, where it is built into the southeast or "black" corner of the Kaaba

[6] The same story is repeated by Humboldt in his *Cosmos*, Vol. 4, Bonn edition. None of the material of this fall has been preserved, and as a like occurrence was reported in the same locality in 1650, we may well feel justified in doubting both.

[7] See The Worship of Meteorites, by Hubert A. Newton, *Amer. Journ. Sci.*, Vol. 3, 1897, pp. 1–14.

and revered as one of the holiest of holy relics. The Anhadra, India, pallasite, which fell as recently as 1880, is stated to have been immediately taken in possession by Brahman priests who erected a brick temple over the spot. People flocked to it in large numbers, bringing offerings of food and flowers and affording a considerable annual income to the wily promoters.

Kidd in his work on *Savage Childhood* (London, 1906) states: That in the case of a new born Kaffir baby, the child is made to inhale the smoke from a burning mixture of various compounds, the most important ingredient of which is a meteorite which has been well burned and then ground to a fine powder. The Kaffirs think that this substance has the power of closing the anterior fontanelle of the baby's skull, of strengthening, and of making firm the bones of the skull, of imparting vigor to the child's mind, and of making the infant brave and courageous. The strength of the meteorite is thought to enter into the child's whole system.

The great Casas Grandes iron (Plate 12), in the National collections at Washington, was found in an ancient Mexican ruin, swathed in mummy cloths in a manner to indicate that it was held in more than ordinary veneration by the prehistoric inhabitants. The Wichita, Texas, iron, known to the Indians of that region for many years, is said to have been set up by them as a kind of fetish, or object of worship or veneration, as foreign to the earth and coming from the Great Spirit. Meteoric iron has also been found upon a brick altar in prehistoric ruins in Ohio, and it is recorded that a stone weighing about a pound, that fell in East Africa in 1853, was secured by the natives, anointed with oil, clothed and decorated, and finally installed in a temple especially prepared for it. Concerning two Japanese meteorites, it is stated by a writer in the *Transactions of the Asiatic Society* that:

> They used formerly to be among the offerings annually made in the temple of Ogi to Shokujo (*Tanabata tsu me*) on her festival, the seventh

PLATE 13

The Cape York Meteoric Iron. Weight 37½ tons. (Courtesy of the American Museum of Natural History, New York)

day of the seventh month. There is no mention of these having fallen on this day in the year, but they were connected with her worship by the belief that they had fallen from the shores of the Silver River, Heavenly River, or Milky Way, after they had been used by her as weights with which to steady her loom.

In the 1830 edition of the *Edinburgh Encyclopedia*, de Guignes relates that a star fell to the ground in China and was converted into a stone, an event which created an extraordinary sensation. The inhabitants of the district, willing to convey a moral lesson to their unpopular emperor, caused these words to be engraved on the stone: "Chi-Hoang-Ty draws near to death and his empire will be divided." As a punishment the emperor condemned the inhabitants to death but died himself the following year, and his empire was divided into several kingdoms.

Not only the actual falls but also the intangible shooting stars excited feelings of unrest in superstitious minds. The oft-quoted and immortal Pepys, under date of March 21, 1667, wrote:

> All the town is full of the talk of a meteor, or some fire, that did on Saturday last fly over the city at night, which do put me in mind that, being then walking in the dark an hour or more myself in the garden after I had done writing, I did see a light before me coming from behind me, which made me turn back my head: and I did see a sudden fire or light running in the sky, as it were, toward Cheapside-ward, and it vanished very quick, which did make me bethink myself what holyday it was, and took it for some rocket, though it was much brighter: and the world do make such discourse of it, their apprehensions being mighty full of the rest of the city to be burned, and the Papists to cut our throats.[8]

[8] It is not strange that in the early days the fall of one of these bodies should be considered of sufficient significance to demand some form of public recognition, even if not of reverence. Such a feeling, according to Brezina (*Proc. Amer. Philos. Soc.*, Vol. 43, No. 176, 1904) found expression about 400 or 500 B.C. in the striking or casting of metal (bronze, silver, or gold) *betyls* or coins, presenting "as a common feature the likeness to conic stones, or obelisks, or to archaic, half-conic simulacra, so that it came about that similar representations of unknown origin were likewise supposed to represent sacred meteorites." Brezina lists and figures forty-one such coins which he classes as (1) betyls representing stones fallen from heaven, and (2) betyls accepted by analogy to represent meteorites. Their authenticity is not, however, generally recognized.

But if the fall of these comparatively small bodies, weighing at most but a few hundred pounds, is accompanied by phenomena so extraordinary as to impart veneration or terror to man and beast over wide areas of country, what must have been the effect produced by the fall of such giants as those of Cape York, Greenland; Bacubirito, Mexico; Willamette, Oregon; or that which formed the Canyon Diablo crater. Fortunate it may be for the individual that he was not a nearby witness of their terrific display, but it is nevertheless to be regretted that their fall was unrecorded, and perhaps unseen as well. The closest imaginable approximation to such a possible display of which we have record, is that of the great meteor of 1860 which left no tangible record of its brief excursion into our atmosphere. The following is abridged from an account of this remarkable visitor, given in the *American Journal of Science*, Volume 30, 1860. The meteor was traveling from north-northwest to south-southeast, or in a direction from Lake Michigan to the Gulf Stream. It was visible over an area at least 1,000 miles in length and 700 or 800 in width. The time of its passage, according to the most reliable witnesses, was estimated at twenty to forty-five seconds, with an actual velocity of some twenty-six miles per second. Its height when seen over Lake Michigan was estimated at 120 miles. This was gradually reduced until over Long Island it was but forty-two miles.[9] The actual dimensions of the luminous mass were from one-third to one-fifth of a mile. When first seen it was in the form of a more or less elongated single body, gradually increasing in brilliancy and throwing off sparks and flashes of light. When about over Elmira, New York, an "explosion" took place and the meteor separated into two principal portions with many subordinate fragments,

[9] In the *Report of the Smithsonian Institution* for 1868 it is stated that the velocity when nearest the earth was 9.76 miles per second, and that its nearest approach to the earth was at about the middle of New York State, where its altitude was 39.19 miles.

PLATE 14

The Willamette Meteoric Iron. (Courtesy of the American Museum of Natural History, New York)

all of which continued on their course, scattering sparks along the track, until at a point south of Nantucket where a second explosion occurred. Shortly after this the meteor passed from view, probably falling into the Atlantic, although it is doubtfully possible that it passed again out of our atmosphere, and went on its way once more with an orbit considerably disturbed and a constitution considerably shattered by its close proximity to the earth.

CHAPTER III

AREAS OF DISTRIBUTION

In many cases of meteoric showers like those mentioned on previous pages, the individual pieces are distributed over oval areas of considerable extent, the longer axes of which are in the direction of flight, the heavier masses being carried the greater distances. The Holbrook, Arizona, shower of July 19, 1912, was estimated by W. M. Foote to comprise over 14,000 individuals weighing from one-tenth to upward of 2,000 grams each, which were scattered over an ellipsoidal area about one-half of a mile wide and three miles long. The Knyahinya, Hungary, fall comprised over 1,000 individuals; that of Laigle, France, between 1,000 and 2,000; and that of Pultusk, Russia, has been estimated to have comprised 100,000. The Hessle, Sweden, fall, according to Nordenskiöld's map, must have been scattered over an area some two miles wide and ten miles in length, in a northwest and southeast direction, while the shower of Mocs, Transylvania, comprising 3,000 or, as estimated by Brezina, 100,000 individuals, was spread over an area three miles in length. The celebrated Coon Butte, or Meteor Crater, find near Canyon Diablo in Arizona, comprised many thousand individuals weighing from one gram to 500 kilograms, scattered over a known area of some four miles radius about the crater (Figure 2), the smaller of these being plainly oxidation residues and the total weight probably twenty tons. In the case of the Homestead, Iowa, fall (Figure 5), the shower was limited to an area of some five by seven miles, though what was apparently the main portion of the shower continued on its

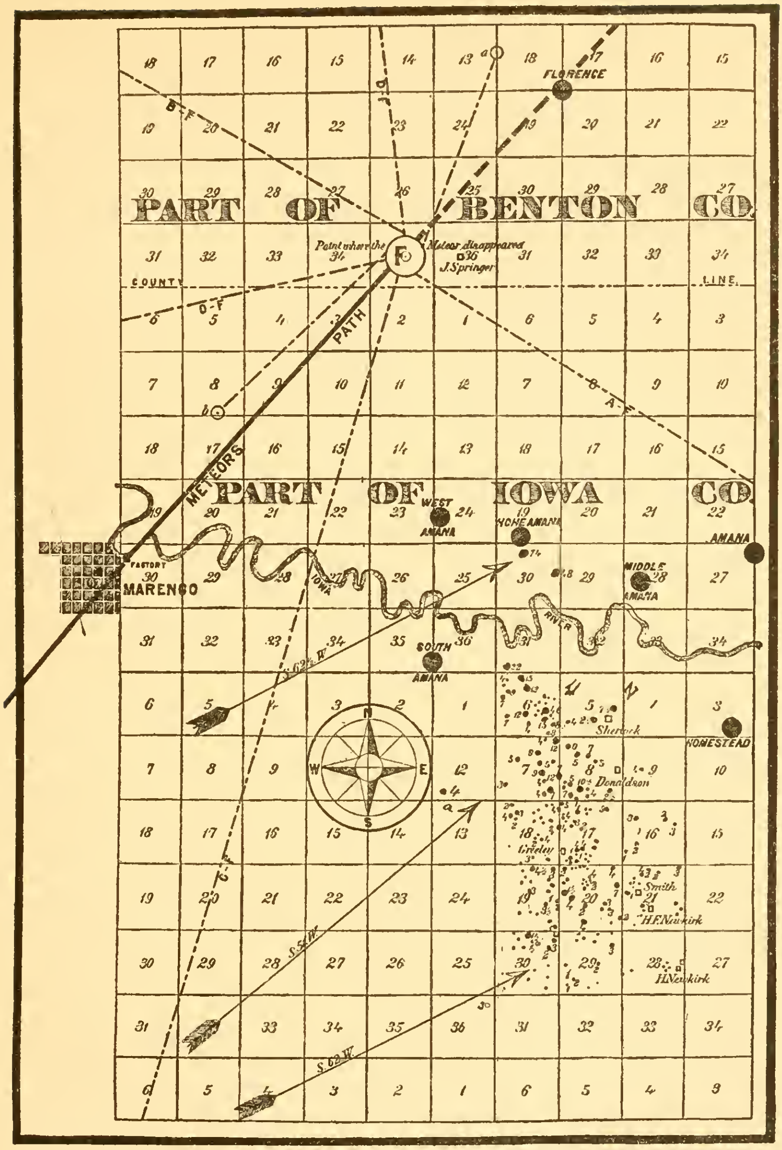


FIG. 5. Map showing areal distribution of stones of the Homestead, Iowa, fall

way and so far as is known did not reach the earth at all. The Guernsey County, Ohio (New Concord), fall comprised over thirty stones weighing altogether some 460 pounds, which were scattered over an elliptical area ten miles long by three miles broad. On the other hand, many falls, as in the case of that of Allegan, Michigan, or Bishopville, South Carolina, are limited to a single stone, or iron, as the case may be.

There is at present no law known which covers the geographical distribution of meteor falls. Indeed, the irregularity of distribution is so great as to render almost hopeless any attempt at a solution. A possible cause which seems applicable to one locality is shown to be utterly inapplicable to any other. Thus the suggestion based on the abundant falls in our southern Appalachians, to the effect that such frequency might be due to the increased attraction of gravity in mountainous regions, is rendered inadequate by the fact that no such increase actually exists, and that, moreover, but two falls have been reported for the entire area of the Swiss Alps; while on the other hand, eighteen have been reported from the flat plains of Kansas with an average elevation of less than 3,000 feet. That the recorded number is due to density of population and hence an apparent increase in the number of observers is negatived by the fact that but one meteorite has as yet been reported throughout the entire Chinese Empire,[1] while India has over 100 to her credit, and Russia sixty-eight. Soil and climate have undoubtedly much to do with the *finding* of the meteorites after they have once fallen and with their preservation, but no single cause that has stood the test of close analysis has as yet been suggested for this inequality. In view of the short life of a meteorite after reaching our soil, and the brief period of falling and observation available for deductive reasoning, it is

[1] Yet Biot, in his *Catalogue général des étoiles filantes*, 1841, records hundreds of such occurrences during the period between the seventh century, B.C. and the seventeenth century, A.D.

perhaps useless to expect a solution of the problem for many years to come.

As bearing upon this, the following tables are of interest:

Geographic Distribution of Meteorites in North America up to 1925

Alabama	11	Maryland	3	Oregon	3
Alaska	1	Michigan	5	Pennsylvania	5
Arizona	7	Minnesota	2	South Carolina	5
Arkansas	2	Mississippi	3	South Dakota	2
California	7	Missouri	11	Tennessee	18
Colorado	9	Montana	1	Texas	24
Connecticut	1	Nebraska	9	Utah	2
Florida	2	Nevada	1	Virginia	10
Georgia	15	New Jersey	1	West Virginia	2
Idaho	1	New Mexico	10	Wisconsin	6
Indiana	6	New York	6	Wyoming	1
Iowa	4	North Carolina	22		
Kansas	18	North Dakota	3	Canada	11
Kentucky	16	Ohio	6	Mexico	44
Maine	4	Oklahoma	1	Central America	3
Total					324

Table Showing Approximate Number, Kind, and Geographic Distribution of Meteorites up to 1925

Country	Irons	Stones	Stony Irons	Totals
North America	209	102	13	324
South America	30	16	6	52
Europe*	29	225	8	262
Africa	25	27	..	52
Australia**	32	17	5	54
India	3	95	2	100
Japan	3	12	..	15
Siberia	10	6	2	18
All Others	7	17	1	25
Totals	348	517	37	902

* Including Great Britain and Ireland.

** Including New Zealand and Tasmania.

Few natural phenomena are more likely to unduly excite the imagination than those attendant upon a fall of meteorites. The suddenness, the unexpected nature of the occurrence, the light and noise, and, perhaps above all, the sensation aroused from the sudden projection of a solid body from seemingly empty space, all have their effect; and it is not surprising that accounts by various individuals are widely variable, dependent upon the flexibility of the imagination, perhaps, more than upon powers of observation. Few persons, however well trained, can look calmly and with judgment upon the phenomenon. Fewer yet can, in the brief space of time, estimate the height of the body when first seen or note such data as may be of service in calculating its rate of progress.

An interesting feature of the phenomenon is the lack of ability on the part of the observer to exactly locate the place of fall, unless, indeed, he happens actually to see it strike the ground. This is due to several causes and, in part at least, to the varying angles at which the stones sometimes enter our atmosphere, which may permit a continuation of flight for long distances beyond the point at which they seemingly must strike the earth, and in part to the fact that one is unable to correctly estimate the distance of bodies falling from a height which may be much greater than supposed. The late H. A. Ward once told the writer of his experience in such matters. He was sitting in front of a house occupying a somewhat elevated position with reference to the rest of the town. Suddenly a meteorite appeared descending from the sky, and fell, he was sure, within a certain square on the lower level. He at once proceeded to the spot, only to find that he was mistaken and that it had fallen "a few blocks away." At this second point the same experience was repeated and the stone finally located some twenty miles beyond the point where he was "certain" he had seen it strike.

An even better illustration was offered some years ago by a meteor passing over the city of Washington. It was first reported to the writer by a man fishing in the Potomac some eighty miles south of the city. He saw it strike—was certain of it—within a half a mile of where he was standing; offered to go and get it if properly reimbursed. As, however, a meteor had passed over Washington, traveling in the same direction, on the same day at the same hour, the offer was not accepted. The meteor was also "seen" by various individuals to strike on the roof of an apartment house within the city limits, and by others to fall in Chevy Chase, a few miles to the north. In both cases supposed fragments were collected and forwarded for examination. Not one proved to be meteoric. By writing to postmasters along the line of direction in which the meteor appeared to be traveling, it was actually traced from where it was first "seen to fall" for nearly 300 miles into northeastern Pennsylvania, and it was still going! If it fell at all, no trace of it has been discovered.

Almost without number are the instances in which stones have been picked up which "were seen to fall" but which prove to be strictly of terrestrial origin. There comes a sudden flash and report, the observer goes quickly to the spot where the meteorite was thought to strike, and there finds an object which had not previously attracted his attention, although he may have been over the ground many times. This is at once assumed to be the meteorite, and in perfect good faith he writes to some museum, announcing his discovery and willingness to dispose of the newly discovered meteorite. There is probably not a museum of importance in the world that does not annually receive one or many such finds which, on examination prove to be glacial bowlders, residual masses of iron ore, or any of the less common materials that strew the ground of the particular locality. The writer has repeatedly had material sent him which was even "warm when picked up" and found it to be but a bowlder which had lain upon the spot where it was found during all the years that have elapsed since the final retiring of the ice sheet of the glacial period. Few lines of investigation are better calculated to unfit one for jury duty where are involved grave questions in human testimony concerning sudden phenomena than that relating to the study of meteorites.

Under particularly favorable conditions, as where a falling meteor has been noted from different standpoints by several observers, it has been possible through plotting the recorded observations of azimuth and altitude to locate the point of probable contact with sufficient accuracy to warrant a systematic search. It was through such means that portions of the Bath Furnace and Cumberland Falls stones were found.[2] Doubtless the meteor which passed over Washington in January, 1921, already referred to, might in like manner have been found had sufficient time been devoted to it, and in cases where there has been a shower, as at Holbrook, Arizona, and elsewhere, there is always the chance of finding more.

Of all instruments and instrumentalities for finding meteorites, where not actually seen to fall, the humble plow and its less humble holder have proved most fruitful. "Found while plowing" has become almost stereotyped through its abundant repetition. The Admire and Anthony finds in Kansas, the Burlington, New York, and Carlton, Texas, finds may be mentioned among the many that have thus been brought to light. The reason for this is almost self-evident, particularly if the region be one free from drift or one of sedimentary rocks only, like our lower Mississippi Valley. The plow strikes an obstruction, which, on examination, is found to be of metal, or, if of stone, unlike anything in the neighborhood; curiosity is excited and it is taken home to hold down a well or barrel cover, where its nature is ultimately dis-

[2] A. M. Miller, *Sci. Monthly*, Nov., 1923.

covered by a chance traveler; or the finder may himself have been of a sufficiently inquisitive mind to send it away (to the Smithsonian or elsewhere) to have its nature determined. The pallasite of Brenham County, Kansas, offers a good illustration of this chance finding. The region is that of a prairie, with deep, stoneless soil. Hence great surprise and curiosity was manifest when the mowing machines and plows struck projecting masses of heavy, dark-colored rocks. Over twenty were found in different parts of the area, weighing altogether about a ton. The larger were collected and utilized in holding down haystacks and barrel covers until their nature and value were discovered.

That so many examples have been found in the flat and treeless prairie lands is thus readily explained. That so many are found in desert regions is due to a lack of vegetable covering to obscure them, and to their long preservation in a dry soil and atmosphere. There is on record the case of a young man in Texas who, on finding a rounded, dark-colored stone unlike others in the neighborhood, sent it away for identification, and on learning its true nature, made a systematic search and found some score of additional individuals which yielded him a very satisfactory pecuniary reward when they were distributed among collectors. These were, however, all products of the same fall.[3] The Canyon Diablo find was of like nature and will doubtless yield still other smaller individuals to chance finders.

Reference is made on page 47 to mistakes that have occurred in the identification of supposed meteoric material, and the question naturally arises: By what means is it possible for one to identify a meteorite even with a reasonable degree of safety? The best and most general rule is an empirical one. Experience in handling and

[3] In this connection it may be well to state that in the few cases in which the ownership of a newly-found meteorite came to the courts for decision, the verdict has been invariably in favor of the owner of the land on which the object was found.

studying will afford safer criteria than any number of tests made by one inexperienced. Nevertheless, there are characters easily recognized that will serve to guide one along the road of probabilities. If the object found is metallic and malleable, *i.e.*, impressible without shattering under the hammer, and found elsewhere than near iron-smelting works, the chances are sufficiently in favor of its meteoric nature to warrant its being examined with care. If, when submitted to a chemist, it reacts not alone for iron but for nickel as well, this is nearly conclusive and it should be judged further by an expert, with particular reference to its crystalline structure. If the object is a stone, or largely of stony matter, it will invariably show, if freshly fallen, a thin, dark crust, sometimes black and smooth, sometimes slightly shagreened. This crust will extend entirely over the surface except where broken in the fall, and the stone beneath shows no signs of fusion or of heat in any degree. Further than this, a freshly broken surface will nearly always reveal little projecting points of metallic iron which can be felt if too small for easy recognition otherwise. With the exception of a few rare cases of basaltic rocks, instances of this kind are unknown among terrestrial equivalents. Beyond this the inexperienced can rarely go, though a chemist may be of some assistance in determining the presence or absence of nickel. Either stone or iron will invariably, if fresh, show the effects of its flight through the air—not by the crust alone, as already mentioned, but by pittings, thumb markings, or piezoglyphs, formed as elsewhere described. If the object "picked up with stones to make a wall" (to quote a line from the poet Frost) fulfills all these criteria, the chances are greatly in favor of its actual meteoric nature.

But, as already stated, meteorites, owing to their peculiar mineral composition, are of an extremely perishable nature and only when almost immediately gathered will they be found fresh and unaltered. The first change manifest is that of oxidation of the iron chloride, lawrencite, which freckles a broken surface with rust-colored spots, and which, if abundant, gradually stains it throughout and perhaps produces disintegration. The same constituent in an iron causes it to sweat with drops of rusty moisture and to ultimately exfoliate and fall to pieces. In some cases, as in that of the Admire, Kansas, stony iron, the oxidation proceeded in such a manner as to actually hermetically seal and protect the inner portion so that when found it resembled nothing more than an irregular lump of brown iron ore. When broken, the unoxidized interior showed its true nature; but unfortunately decomposition at once set in again, and in spite of utmost care, this interesting meteorite is represented in collections today by crumbling fragments which can be prevented wholly from destruction only by immersion in a petroleum distillate or some similar fluid. The trouble is, of course, not due to the chloride alone, since metallic iron and the iron sulphide, troilite, are themselves vulnerable to the attacks of a moist atmosphere, and given time enough, the results will be the same.

The so-called "shale balls" once so common in the Canyon Diablo region, are but oxidized masses which in some cases, when broken, still show a residual nucleus of metal like an oyster in its shell. But for the dryness of the climate, these too would doubtless have long since become unrecognizable as meteorites.[4]

On account of the halo which naturally surrounds an object of such mysterious origin, meteorites have been eagerly sought by collectors—so eagerly, indeed, that stones and irons have been divided and subdivided to a degree bordering upon the absurd and far removed from scientific. The desire on the part of collectors to secure representatives of the fullest possible number of falls has not only led them to bid prices foolishly high but

[4] The writer brought several shale balls with such nuclei to Washington only to have them go to pieces notwithstanding all the care that could be exercised.

has caused a stone—if of only moderate size—to be broken into bits and so widely distributed that it has been impossible in later years to secure enough for study. Catalogues of collections have been printed in which certain rare falls were represented by fragments weighing but 0.1 or 0.2 of a gram, or a little larger than the point of an ordinary lead pencil. Prices have soared accordingly and instances may be cited in which five to ten dollars a gram has been paid. The small meteorite which fell in Kilbourn, Wisconsin (Plate 40), in 1911, and passed through a board in the roof of a barn, sold as high as seven dollars a gram, largely on this account, as it was a stone of a common chondritic type. Obviously a meteorite has no *actual* value and these prices are not only wholly artificial and unscientific, but silly. It should be added that this condition is due largely to the mere collector rather than to the serious student. Ambitious heads of departments in our public museums are, however, by no means blameless.[5]

In the now commonly adopted system, valuation of a meteorite is based upon the following eight factors, of which the first three are considered of primary importance:[6]

[5] The meteorite of Juvinas, France, of which there was originally upwards of fifty kilograms, has been broken up and distributed among sixty-two collections, of which three report one gram each and nineteen others less than ten grams each; that of Stannern, Austria, of which there was upwards of thirty-eight kilograms, has likewise been distributed among ninety-six collections of which the Vienna museum has about one-sixth, four others upwards of a kilogram, and the remainder, scattered amounts of from one to 850 grams. Of the Bialystok howardite, of which there was originally upwards of two kilograms, but 627 grams are now known, distributed among eighteen collections, of which the largest sample is but 120 grams; no analysis has been made through want of material. Of the Frankfort, Alabama, stone, weighing originally but 615 grams, the location of 535 grams is accounted for, distributed among eighteen collections, the largest sample being but 255 grams and four catalogued as mere "splinters." The climax is reached, however, in the case of the stone of Nobleboro, Maine, of which there was originally from four to six pounds; but seventy-eight grams are now accounted for, distributed among eleven collections, seven of which record only "splinters."

[6] See H. A. Ward, Values of Meteorites, *The Mineral Collector*, Sept., 1904; and W. M. Foote, Factors in the Exchange Values of Meteorites, *Proc. Amer. Philos. Soc.*, Vol. 52, 1913.

1. Present known weight of the fall.
2. Petrographic composition.
3. Number of owners of pieces.
4. Material which may still come to light.
5. Difficulty of obtaining from present holders.
6. State of preservation.
7. Historical interest.
8. Was it seen to fall?

Obviously such a ratio is based almost wholly upon the demands of the mere collector—he who wants a thing chiefly because it is rare. To the real student only the second, sixth, and eighth items are of more than secondary interest, and several, such as the third and fifth, of none whatever. Those upon which a real scientific value may be placed are: petrographic characters, details of fall, and state of preservation.

Nearly all large public museums now have meteorite collections, the largest being in Vienna, Paris, and London abroad, and Chicago, New York, Washington, and Harvard and Yale universities in America. In one or two instances their numbers in representative fragments and more or less complete individuals run as high as 500 to 700 distinct falls and finds.

CHAPTER IV

THE NUMBER, SIZE, AND FORM OF METEORITES

It is estimated by astronomers, as elsewhere stated, that 400,000,000 meteors penetrate our atmosphere daily, and of these 20,000,000 are of sufficient size to form shooting stars. It must be remembered, however, that a particle weighing not more than a gram, and of which, therefore, it would require between 400 and 500 to make a pound, is of sufficient size to be visible after sundown. Of these 20,000,000, comparatively few are found even if they survive to reach the earth, as may readily be imagined, being too small for recognition.[1] Moreover, but one-fourth of the earth's surface is land and but a comparatively small portion of this so occupied by intelligent human beings as to make finds probable even were the falls noticed, while falls during daylight of any but large stones would be likely to be overlooked or disregarded everywhere. It will in this connection be well to call attention to the enormous discrepancy between the *apparent* and *actual* sizes of these falling bodies. How great this is may be judged from the fact that very moderate-sized stones have been reported in sizes up to that of the full moon when seen at distances of twenty to one hundred miles. The Hraschina fall, which yielded but two irons weighing sixteen and seventy-one pounds, was estimated to have an apparent diameter of 3,000 feet.

[1] The number that fell during the five or six hours of the shower of Nov. 12, 1833, was estimated by an observer in Boston at 250,000. There was no sound and, so far as known, not one came to earth.

According to G. von Niessel,[2] Herschel concluded, from a comparison of the light power of a shooting star at a given distance with that of a given mass of gas, that a meteor of first magnitude weighs on the average very few grams, and that the smaller meteors weigh only a fraction of a gram. By similar comparisons with the Drummond light, V. F. Sands, with reference to the Leonids of 1867, found the following estimates:

Apparent brightness that of	Mass or weight of corresponding meteor
Jupiter	0.67 grams
Sirius	0.45 "
First magnitude star	0.06 "
Second magnitude star	0.02 "
Third magnitude star	0.01 "
Fourth magnitude star	0.006 "
Fifth magnitude star	0.004 "

F. Berwerth estimated that but about 900 recognizable meteorites fall annually upon the earth,[3] and of this number, three-fourths would be lost in the oceans, leaving but 225 for the land. In addition it must be remembered that the mineral nature of a meteorite is such that few of them survive for any prolonged period after falling, except in very dry regions. Even of these but a small fraction (not more than three or four annually) find their way into collections. Ward, in 1904, listed 815 known individual meteorites, of which 680 were represented in the various collections. Prior, in his catalogue of 1923, listed 849. A still more recent (1925) count places the number at 902.

The smallest known meteorite comprising an entire fall is that of Mühlau, Austria. This is now in the Vienna Museum. It weighs five grams, and being a stone, is about as large as a filbert, or the end of one's finger. The

[2] Determination of Meteor Orbits in the Solar System, *Smithsonian Misc. Coll.*, Vol. 56, No. 16, 1917.

[3] Schreibers made an earlier estimate of 700.

largest known meteorite is the metal monster brought by Peary from Cape York, Greenland. This weighs, according to the authorities of the American Museum of Natural History, 37½ tons, or 34,014 kilograms.[4] Following in the order of decreasing sizes are the Bacubirito iron of Mexico (Plate 15), estimated to weigh 27,500 kilograms; the Willamette iron of Oregon, weighing 14,140 kilograms; and the Bendego iron of Brazil, weighing 5,370 kilograms. All of these, it will be noted, are of metal, the largest single stone thus far found being that of Estacado, Texas, which was reported to have weighed 290 kilograms. Unfortunately this has been cut up and distributed. The largest individual of the Knyahinya fall weighed 250 kilograms. The next largest is that of Selma, Alabama, which weighs 138.6 kilograms. The comparatively small size of the stony forms must be ascribed to their brittle nature which causes them to break up in the latter portion of their flight. For purposes of comparison consideration should be given to the total weight of all the individuals of a fall, so far as obtainable. That of the Knyahinya shower was nearly 500 kilograms; of the Estherville, 337 kilograms; of the Mocs, perhaps 300 kilograms; of the Long Island, Kansas, 1,976 kilograms; and, according to Foote's estimate, for the 14,000 individuals of the Holbrook shower, 218 kilograms.

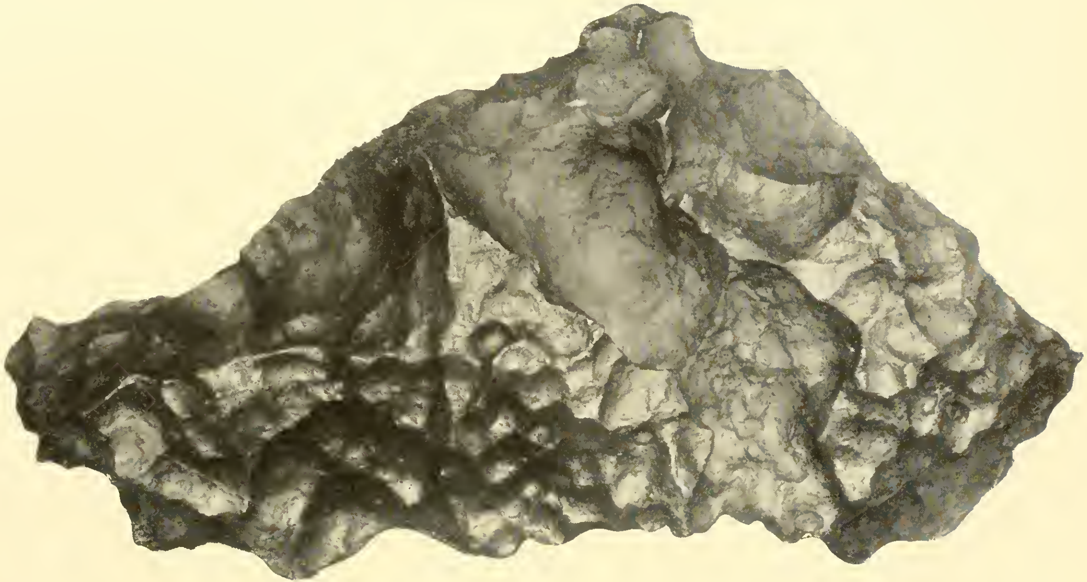
The total weight of all known falls and finds of meteoric material to be found in the various collections was estimated by Wülfing in 1897 to be but 32,500 kilograms, or a little short of 40 metric tons. This, of course, was not the total weight of the falls, nor did it include the giant masses since reported from Cape York, Bacubirito, Willamette, and Quinn Canyon, nor the estimated total of the Canyon Diablo and various Mexican falls. A recent estimate of weights of all known falls and finds, up to 1927, including the large masses mentioned and those since Wülfing's time, gives a total of 219,151 kilo-

[4] A kilogram equals 2.205 pounds avoirdupois.

PLATE 15

The Bacubirito, Sinaloa, Mexico, Meteoric Iron lying as found but partially uncovered

PLATE 16



Iron Meteorite: Owens Valley, Inyo Co., California. Found by sheepherder in 1913, and presented to the National Museum by Mr. Lincoln Ellsworth. Length 65 centimeters; weight 193.17 kilograms (425 lbs.). The iron shows to excellent advantage the so-called "piezoglyphs," or "thumb markings" grams, or 483,008 pounds. The most that can be said concerning such an estimate is that it is underweight to an indefinite extent.[5]

It was long since conceded that the original form of a meteorite was that of a fragment, and that in the majority of cases this fragmentation had been renewed after the body entered the earth's atmosphere. The processes by which this last phase was brought about have been sufficiently dwelt upon elsewhere. The various forms presented by the fallen body are due to the original form of the fragment and the burning away of the surface to an extent dependent upon the speed of the meteorite, its mineralogical nature, and state of aggregation. Friable stones may continue to break throughout their course, giving rise to fragments quickly rounded by burning and resulting in irregularly rounded, pebblelike forms coated with the black crust. Firmer, more resistant stones may give rise to sharply angular forms, only the edges of which become rounded and the surface smoothed. When of sufficient size or of a form to hold their position for any length of time, such stones become smoothed on the face that is foremost—the nose, or the "*brustseite*" as the Germans call it—and not infrequently show radial lines or furrows (Plate 34) extending back toward the rear, caused by the rush of the air. So constant are these that it is possible for one conversant with the subject to tell which face of any meteorite was foremost in its flight. The numerous depressions, thumb markings, or *piezoglyphs* such as are shown by the Owens Valley iron are due in part to the unequal resistance of various portions of an unhomogeneous character. (Plate 16.) These markings at times so closely simulate those made by a human hand as,

[5] It will be recalled (see page 4) that, on the basis of an annual deposit of 93,000 tons of meteoric matter, it was estimated that it would require 350,000,000 years to form an accumulation one inch in thickness over the entire earth. An incidental effect of this increase in weight would be a slowing up of the earth's speed of rotation amounting to .001 second in a million years. An equally interesting estimate is that the passage of these meteors through our atmosphere generates yearly as much heat as that received from the sun in 0.01 of a second.

in one instance at least,[6] to have given rise to the thought that the stone was soft and plastic when found and received the impress of the fingers and palm when pulled out of the earth in which it had buried itself! Nodules of troilite, or troilite and carbon, such as are so conspicuous a feature of the Canyon Diablo iron, quickly yield to the rush of air, burn away and leave pits or holes perhaps extending quite through the mass.[7]

That flattened irons like those of Oakley, Idaho; N'Gourema, Africa; Cabin Creek, Arkansas; and Algoma, Wisconsin, should come broadside through the atmosphere instead of edgewise may at first seem strange but that they do so is proven beyond controversy by their surface markings; moreover, that the position is normal has been mathematically demonstrated.

The rapidity with which the surface of a stone becomes fused and its irregularities smoothed in the short period of flight is wonderful. Instances are by no means rare in which individual stones belonging to one and the same fall have acquired crusts of the first, second, and even third order, due to successive breakings and the fusion of each successively exposed surface. Naturally, owing to lessening speed, each new crust is thinner than the older, and may be but a mere film scarcely distinguishable, affecting the more prominent points on the rough surface.

It is doubtless due to their refractory nature that iron meteorites come to earth in larger sizes than stones, and this notwithstanding the more rapid combustion they may undergo owing to the increased rapidity of flight—if we accept this as demonstrated. However this may be, it is well known, as elsewhere stated, that individual irons vastly outweigh the stones. The largest amount of stony material constituting a single fall is that of Knyahinya

[6] The Haraiya meteorite. *Rec. Geol. Surv. India*, Vol. 35, 1907, p. 91.

[7] See also Berwerth's *Etwas über die Gestalt und Oberfläche der Meteoriten*, *Festschrift des Naturwissenschaftlichen Vereins an der Universitat Wien*, 1907.

noted above; the largest *complete* individual reported is that of Estacado which weighed 290 kilograms (638 pounds) while the single mass of metal brought from Cape York by Peary weighed 34,014 kilograms (75,000 pounds). On the supposition that these larger masses suffered a loss equal to that estimated by Wimperis, the originals were surely of considerable size, though just what limit is to be placed on the word "considerable" is problematical.

Showers of iron meteorites, such as have been described in the case of stones, are quite unknown. The apparent anomaly in the Canyon Diablo occurrence is in all probability due to the fact that the irons fell, not as single individuals, but as loosely aggregated masses composed perhaps of troilite or other easily decomposable material enclosing the metal which has since been liberated through decomposition. The form of the smaller irons of this fall, with their sharp points and edges, is conclusive evidence of their not falling singly.

The coarse crystallization of many meteoric irons, particularly the octahedral varieties, has been considered by some indicative of very slow cooling, and this in itself would indicate masses of some magnitude. Perhaps one might gain a better perspective through a consideration of the conditions under which such a mass could have originated. Owing to the abundant illustrations that have come to earth of meteorites composed mainly of silicates with merely a trace of metal, through all intermediate forms to those almost wholly metallic, it is possible to conceive of the latter as simply metallic segregations out of stony masses of much greater dimensions, in which case it would not be difficult to imagine the mammoth forms mentioned as from bodies of planetary sizes. This is, of course, purely speculative.

One of the most suggestive meteoric masses that have recently come up for consideration in following this line of thought is that of Cumberland Falls, Kentucky, which fell April 9, 1919. This meteorite, it will be remembered, is a siliceous breccia,[8] composed of fragments of two quite different types, the one a coarse, nearly white pyroxenite;[9] and the other a compact, nearly black chondritic[10] stone. (See Plate 17.) That the original mass from which they were derived was broken either by impact, explosion, or crushing into fragments which were then intermingled and recompacted, is self-evident. Judging by comparison with terrestrial rocks, one would consider the stone a volcanic breccia, *i.e.*, a recompacted mass of fragments produced through explosive volcanic action. Whether both kinds of stone were from the same or different volcanoes is immaterial. They were intermingled and then subjected to sufficient compressive force to bring about the present degree of firmness. That this compression could be brought about by weight of overlying matter is doubtful. In all probability it was the result of such crustal movements as are operative in producing sharp folding. The degree of compactness, it is to be observed, is considerable—enough to permit the production of a smooth surface and a polish. It is well to note incidentally that the absence of secondary minerals, unless the metal be so considered, is indicative of an absence of moisture of any kind. Particular attention is called to the fact that the present structural features can seemingly be accounted for only on the basis of a parent mass of no inconsiderable size—one in which crustal stresses, as in our own planet, would result in compression and consequent reconsolidation of fragmental detritus as suggested in the original descriptive paper.[11] There is seemingly no escape from the conclusion that the source of this meteorite was a body of planetary dimensions, though

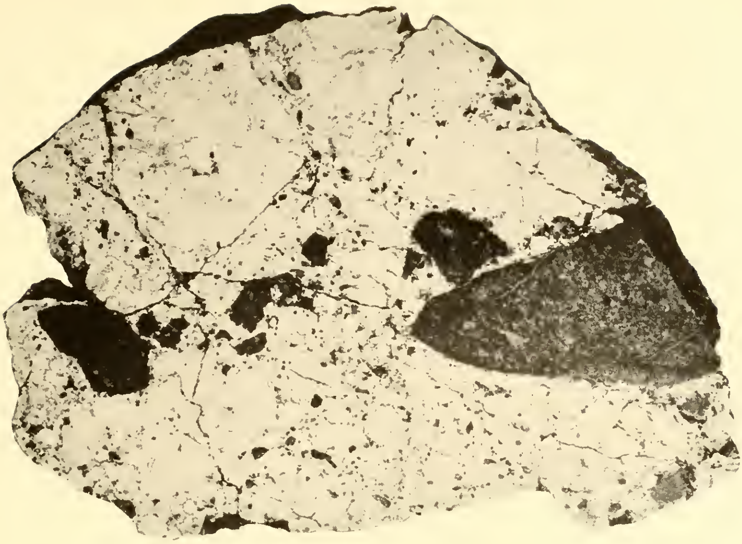
[8] A "breccia" is a rock made up of recompacted fragments.

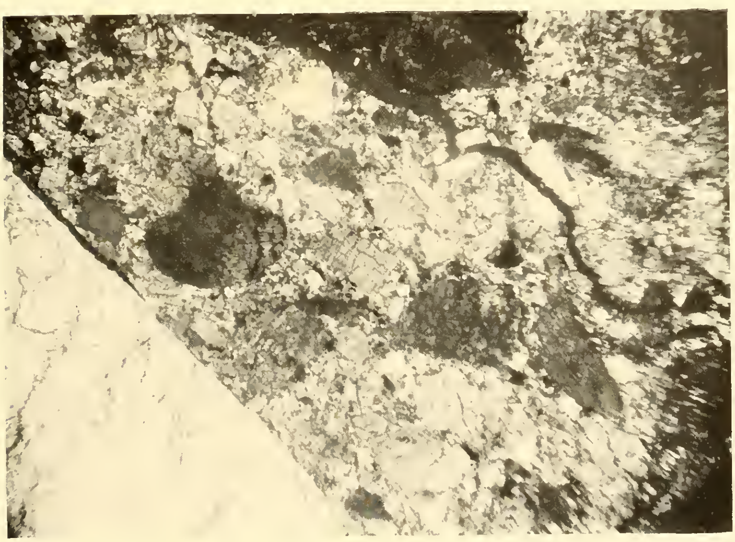
[9] A "pyroxenite" is an igneous crystalline rock composed largely of the mineral pyroxene.

[10] Chondritic structure, for explanation see page 75.

[11] *Proc. U. S. Nation. Mus.*, Vol. 57, 1920, pp. 97–105.

PLATE 17





2

(1) A polished slice of the Cumberland Falls, Kentucky, meteoric stone about natural size and (2) a portion of the same magnified

whether or no a portion of Olbers's lost planet must be left for astronomers.

Elsewhere mention is made of the possibility that distant nebulous celestial masses may be of meteoric material. That there exists in the far reaches of space a considerable and incalculable quantity of meteoric or cosmic material in the form of dust is unquestionable.[12] That a portion of it comes to earth is beyond reasonable doubt and obviously there is no occasion for placing a downward limit on the size of meteoric particles. Moreover it is obvious that the burning meteorites in the upper air leave a residue which must sometime find its way to earth in dustlike form. "Cosmic dust" has come to be considered an actuality, though a large part of the material examined and described under this name is of terrestrial origin. Here mention will be made only of dusts found under conditions such as to make their sources problematical, and the determination of which is dependent upon the kinds of material of which they are composed rather than upon their mode of occurrence. The universally prevalent nature of dusts of some kind, it may be stated, is little realized by the casual observer, who can, however, be quickly brought to a condition of realization by so commonplace a method as that of viewing a sunbeam coming from a narrow opening into a darkened room.

Naturally there are great, if not insuperable, difficulties in determining from mode of occurrence alone what might have been the possible source of a deposit. Not merely do volcanoes occasionally eject dust particles so high in the air that they may be even years in settling to earth, as was the case with Krakatoa in 1883, but the winds under favorable conditions will transport fine material, such as the ejectamenta from blast furnaces in manufacturing districts, to such heights and such distances

[12] "L'espace autour du soliel est, on le sait, rempli de matère cosmique, et de matière cosmique, et de matière cosmique de tous degrés de tenuité et de grosseur." Moigno's *Cosmos.*

that the original sources become problematical. The best points for observation and collection of materials, and those where there is least danger of contamination, would appear to be high mountain peaks and other regions covered over many miles of area with perpetual ice and snow.

But few instances need be mentioned. Von Lasaulx, who examined a large number of samples of dust from various sources, found them to consist of well-recognized terrestrial particles, sometimes volcanic and sometimes wind-swept products of gneissic and granitic rocks. Dust obtained from the melting of pure snow yielded likewise only terrestrial material. On the other hand, dust collected from the Chilean Cordilleras at heights of from 11,000 to 16,000 feet and examined by K. Stolp and A. E. Nordenskiöld, were by both, on account of the mineral composition, relegated to a cosmic—"*weltenraum*"—source. O. Silvestri arrived at a like conclusion from an examination of dust which fell in Catania.

In 1880, a committee from the British Association reported an examination of dusts from the open Atlantic and the Red Sea. These had been commonly regarded as meteoric. It was conclusively shown that they were terrestrial and composed of the fine sands driven from northern Africa. Three samples of dust collected from snow and ice in the Himalayas and remote from manufacturing establishments or habitations of any kind contained spherical particles of magnetic iron and minute shreds of native metal. These were thought to be of meteoric origin. A. E. Nordenskiöld, in his Greenland expedition of 1870, collected from holes in the ice a fine gray powder which he called *cryoconite*, which contained particles of metallic iron and gave reactions for cobalt and copper but consisted principally of white, angular particles of feldspar and augite. Later, in 1873, he found minute rounded grains of metallic iron in hailstones that fell at Stockholm, Sweden. In both cases the metallic particles were considered meteoric.

The historically dark days of 1090, 1203, 1547, and 1706, in Europe, were thought by Chladni and others to be caused by clouds of meteoric dust cutting off the sun's rays, though this may now be considered doubtful. Dust which obscured the sun for two days of 1840, in Russia, was found by Ehrenberg to be made up of diatoms and other organic and inorganic matter from terrestrial sources.

Perhaps in this connection one might refer to the meteoric material dredged during the *Challenger* expedition from almost abyssal depths of the South Pacific Ocean, far removed from possible land contamination. This consisted of spherical, chondrule-like particles of metal and pyroxenes, identical with the chondritic forms of meteorites and unlike anything of known terrestrial origin. While it is true that a large part of this might have arisen from the breaking up (explosion) of meteorites as they approach the earth and are in our atmosphere, it is a fair assumption that a portion may have been derived from the remote original source of the meteorite itself.

On the whole it is fair to assume that, regardless of all discrepancies in reports, there is at all times and everywhere an imperceptible rain upon the earth of meteoric dust, though so contaminated with that of terrestrial origin as to make its detection difficult.

CHAPTER V

THE COMPOSITION AND STRUCTURE OF METEORITES

There are only two avenues to our knowledge of the universe outside of us, one being light, by the agency of which the motions of the heavenly bodies are revealed to us, while the other consists in the masses of matter that come to our earth from that outer universe.[1]

Realizing that our earth is but one of a myriad of bodies flying through space, one's interest is naturally aroused by the consideration of how it agrees both in composition and structure with its distant fellows. Such a determination can be made only (1) through the agency of light, and (2) through the aid of chemistry and mineralogy. With the aid of the spectroscope it was long ago shown that the sun and more distant star bodies were of the same elemental composition as the earth. It failed, however, to show how these elements were combined and their relative abundance. These questions can be solved only by a study of the solid bodies that come to us from space—in other words, from meteorites. It is for this reason that the study of meteorites is so interesting and important. To be able to show that there is throughout all known space a practical sameness of material, solid, liquid, or gaseous, is indeed a wonderful accomplishment. Equally wonderful is it to show that the form of combination of these elements is to a very considerable extent the same as on our earth, and when different, due not to a variation in chemical affinities but to surrounding conditions, and particularly diminishing quantities of certain elements common to our earth and its atmosphere.

[1] Humboldt as quoted by Maskelyne.

Through the aid of chemical analyses and the study under the microscope of meteorites that have been cut into small slices so thin as to be translucent if not transparent, we have been able to determine the form of combination of the various elements, the kinds of minerals resulting, and the various processes of rock consolidation and crystallization, just as in the case of their terrestrial counterparts. What is the result?

We have learned that out of the eighty-four known elements but twenty-eight occur in meteorites in sufficient abundance to need mention here. The most abundant of these, named in alphabetical order, are aluminum, calcium, carbon, iron, magnesium, nickel, oxygen, phosphorus, silicon, and sulphur. In smaller quantities, sometimes so slight as to require careful work for their detection, are chlorine, chromium, cobalt, copper, hydrogen, iridium, lithium, manganese, nitrogen, palladium, platinum, potassium, ruthenium, sodium, titanium, vanadium, and probably also argon and helium. The presence of antimony, arsenic, gold, lead, strontium, tin, and zinc have from time to time been reported, but recent investigations have thrown doubt upon the accuracy of the determinations.[2]

Under the conditions prevailing upon the surface of the earth and to an unknown extent elsewhere, most elements tend to combine, an element like carbon tending, for example, to combine with oxygen and calcium to form the carbonate of calcium known by the mineralogical name of calcite. It sometimes happens that an element has a very weak combining power—is neutral—and makes very few combinations, as is the case with the element nitrogen. Others which would combine are prevented by the absence, or insufficient quantity, of the elements for which they might have an affinity. Oxygen for in-

[2] See G. P. Merrill, *Mem. Nation. Acad. Sci.*, Vol. 14. The results were obtained through *chemical* analyses. It is probable that by means of the spectroscope other constituents in extremely minute proportions could be found. See Hartley and Ramage in *Sci. Proc. Royal Dublin Soc.*, Vol. 8, Part 6, No. 68, 1898.

stance has a strong affinity for iron. When, as in meteorites, we find certain elements, as iron, free (*i.e.*, uncombined), we feel safe in assuming that that particular meteorite was formed in a distant region of space where there was a deficiency of oxygen as compared with our atmosphere, which is certainly an interesting item in what may be called the life history of a meteorite. That the conditions were not wholly dissimilar is, however, apparently shown by the presence in meteorites of certain minerals characteristic of terrestrial rocks as well.

FIG. 6. Diamond crystal out of Canyon Diablo meteorite. Actual size about 1/100 of an inch. (After O. W. Huntington)

The following list comprises the meteoric minerals found in both meteoric and terrestrial rocks: olivine; the pyroxenes; the plagioclase feldspars; apatite; magnetite; chromite; quartz; pyrrhotite; free carbon; and rarely, the diamond in microscopic quantities. These are all found in terrestrial igneous rocks of the nature of basalt and peridotite. The meteoric minerals found rarely, if ever, in terrestrial rocks are the various alloys of iron and nickel known as kamacite, taenite, and plessite; the nickel-iron phosphide, schreibersite; the iron monosulphide, troilite; the iron and chromium sulphide, daubréelite; the iron protochloride, lawrencite; the calcium and titanium or zirconium oxysulphide, osbornite; the calcium sodium phosphate, merrillite; the iron and nickel carbide, cohenite; an isotropic feldspathic mineral called maskelynite; and a form of silica called asmanite, which may after all be the same as the terrestrial mineral, tridymite.

With this much in the way of elemental and mineral composition it will now be well to consider the total average composition of meteorites of various kinds and to compare them with the rocks composing the available portion of the earth's crust. In doing this however, we have first to remark that the meteorites are roughly classified into three main divisions: (1) those that are practically all metal, known as iron meteorites, or meteoric irons; (2) those consisting of a spongelike mass of metal the interstices of which are occupied by silicate minerals—mainly olivine—known as stony irons or pallasites; and (3) those which are composed almost wholly of stony-silicate minerals, known as meteoric stones, or aerolites. The known relative proportions of these have been given as below:

Total weight of all known meteoric irons	195,643,183 grams
Total weight of all known stony irons	13,884,118 grams
Total weight of all known meteoric stones	9,623,664 grams
Total	219,150,965 grams (483,008 pounds)

AVERAGE CHEMICAL COMPOSITION OF METEORIC IRONS

Iron (Fe)	90.63%
Nickel (Ni)	8.51
Cobalt (Co)	0.59
Phosphorus (P)	0.17
Sulphur (S)	0.04
Copper (Cu)	0.02
Chromium (Cr)	0.01
Carbon (C)	0.03
Total	100.00%

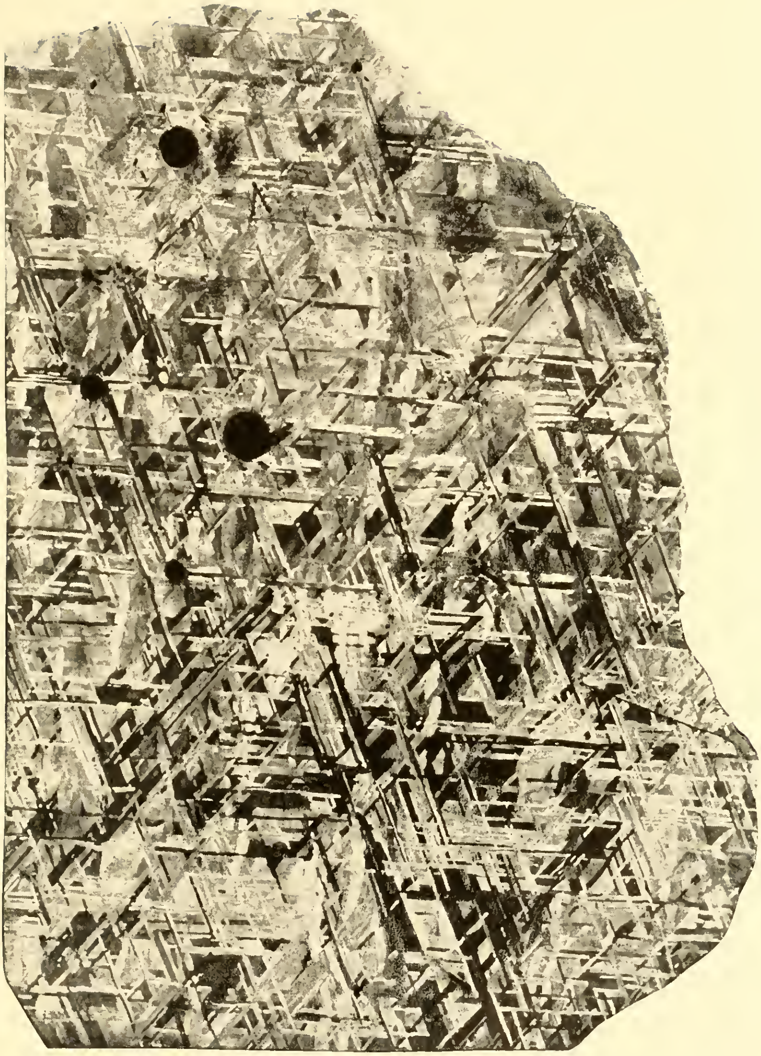
AVERAGE COMPOSITION OF STONY-IRON METEORITES (PALLASITES)

Silica (SiO_2)	20.20%
Ferrous Oxide (FeO)	7.46
Magnesia (MgO)	23.55
Iron (Fe)	43.56
Nickel (Ni)	4.94
Cobalt (Co)	0.29
Total	100.00%

Average Composition of (I) Stony Meteorites, (II) Terrestrial Peridotites, (III) Rocks of the Earth's Crust

Constituent	I	II	III
Silica (SiO_2)	38.68	37.78	59.93
Titanic oxide (TiO_2)	.18	0.58	.74
Tin oxide (SnO_2)	None	....	....
Zirconium oxide (ZrO_2)	None	....	.03
Alumina (Al_2O_3)	2.88	3.11	14.97
Ferric oxide (Fe_2O_3)	....	2.41	2.58
Chromic oxide (Cr_2O_3)	.47	0.19	.05
Vanadium oxide (V_2O_3)	Trace	....	.02
Metallic iron (Fe)	11.98	....	....
Metallic nickel (Ni)	1.15	....	....
Metallic cobalt (Co)	.07	....	....
Ferrous oxide (FeO)	14.58	18.36	3.42
Nickel oxide (NiO)	.48	0.18	.03
Cobalt oxide (CoO)	.06	....	....
Lime (CaO)	2.42	3.06	4.78
Barium oxide (BaO)	None	....	.11
Magnesia (MgO)	22.67	28.38	3.85
Manganous oxide (MnO)	.29	0.31	.10
Strontium oxide (SrO)	None	....	.04
Soda (Na_2O)	.87	0.68	3.40
Potash (K_2O)	.21	0.32	2.99
Lithia (Li_2O)	Trace	....	.01
Water (H_2O)	.75	3.79	1.94
Phosphoric acid (P_2O_5)	.26	0.10	.26
Sulphur (S)	1.80	....	.11
Copper (Cu)	.014	....	....
Carbon (C)	.15	....	....
Chlorine (Cl)	.08	....	.06
Fluorine (F)	None	....	.10
Carbonic acid (CO_2)	(?)	0.75	.48
	100.044	100.00	100.00

These figures are of interest when we consider that the peridotites, which of all terrestrial rocks most nearly compare with meteorites, are of an igneous nature and of comparative insignificance as components of the earth's crust. They occur only as *intrusives*, that is, they have



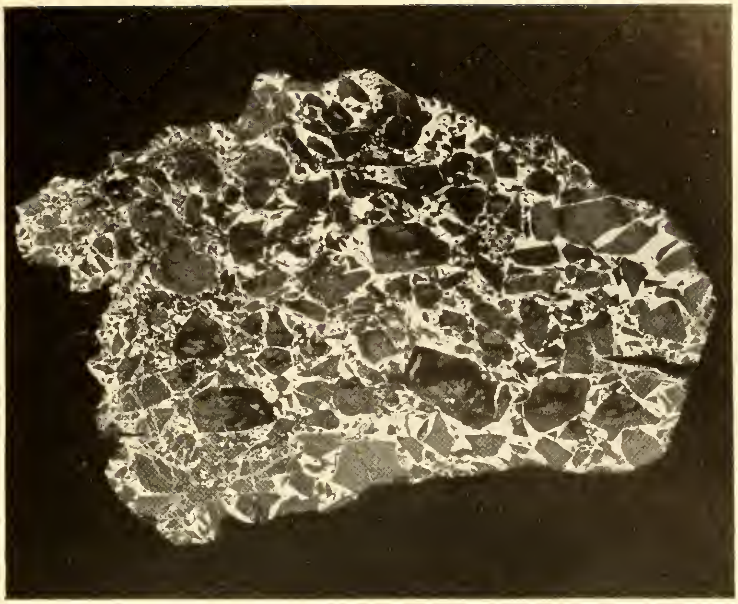
Etched surface of a slice from the Casas Grandes Meteoric Iron

been forced up in a molten condition from unknown depths and intruded into and between the beds of overlying rocks. Their mineral nature is essentially the same as that of the meteorites excepting that they frequently have undergone more or less alteration in which water and oxygen have taken a leading part, and contain no unoxidized metal. A striking and almost sensational similarity lies in the fact that they are sometimes diamond-bearing, as are also meteorites though, so far as now known, only on an almost microscopic scale. The world's supply of diamonds both in South Africa and the United States comes from terrestrial peridotites. How widely separate the stony meteorites and peridotites are from the rocks of the earth's crust, taken as a whole, is shown in column 3 of the last table. It will be noted that the meteorite is some 20% lower in silica, 11% lower in alumina, 12% higher in metallic iron, and nearly 20% richer in magnesia. It is therefore evident that, so far as shown by the exterior crust, the earth could never have originated from an agglomerate of meteoric matter of a nature of that coming today. One can only assume that the meteorites now falling are of a quite different type from those of the geological yesterday; or else, as seems probable, the exterior portion of the earth has undergone an extensive alteration and its true meteorlike nature is to be learned only by borings many thousands of feet in depth. There have thus far been found among meteorites no rocks resembling granite and the more acidic igneous rocks, nor of gneiss, schist, limestone, sandstone, nor indeed any of the great series of sedimentary and metamorphic rocks of which the earth's crust is composed. Nor has there yet been found anything truly suggestive of the one-time presence of organic life. The statement once made that our earth if broken up would yield materials of a meteoric nature is only to a certain extent true, for it would yield also a vast amount of material of a nature wholly unlike known meteorites.

In the preceding pages we have set forth something of the chemical make-up of the several classes of meteorites. The physical condition and arrangement in the mass of these various constituents is interesting and at times radically different from that found in terrestrial rocks. Indeed the conditions are so marked that one versed in the subject can often pronounce at once regarding the meteoric character of a submitted stone, even though not seen to fall, and without the aid of chemical or microscopic tests. As it would be very difficult to give a clear impression of the curious structures found in meteorites by word description alone, the reader is invited to consult carefully the illustrations of this chapter, which reproduce photographs made with the microscope.

1. The All-Metal Meteorites: Siderites

Metallic meteorites, as has been stated, are composed almost wholly of iron with a small and variable percentage of nickel. In the main, these metals are combined in meteorites to form two alloys, named respectively kamacite and taenite. Each of these alloys, in nine metallic meteorites out of ten, is likely to occur in the form of thin plates separated by irregular portions of a third alloy called plessite which fills the interstices. Now the characteristic feature of the matter is that the thin plates of kamacite and taenite tend to lie parallel to the faces of a possible octahedron such, for example, as might be formed by putting two pyramids, in shape like the great pyramids of Egypt, base to base. Figure 7 is used to show the appearance of these markings as dependent upon the angle at which the section is cut. To reveal this structure clearly, as shown in Plate 18 (which is from the 3,000-pound mass of the Casas Grandes iron) it is necessary to cut and polish a flat surface and etch it with dilute acid. Such markings are called Widmanstätten figures, after their discoverer. In thick-



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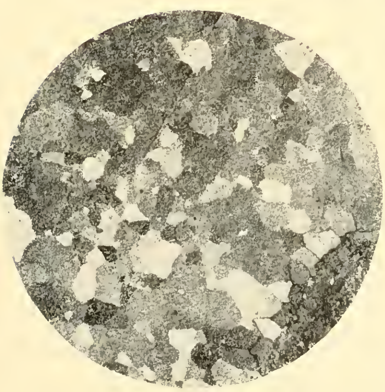

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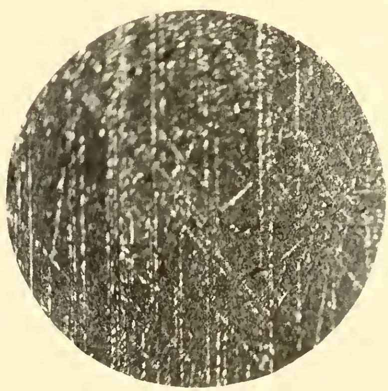
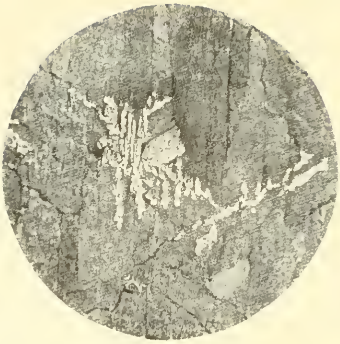


3

(1) A polished surface of a fragment of the Admire, Kansas, pallasite.
(2 and 3) Granular and hexahedral structure of meteoric irons

PLATE 20



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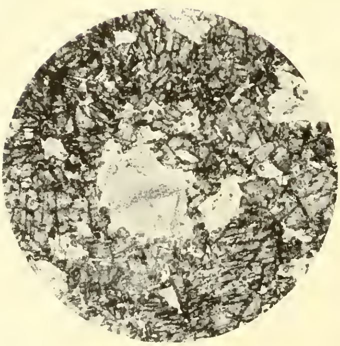

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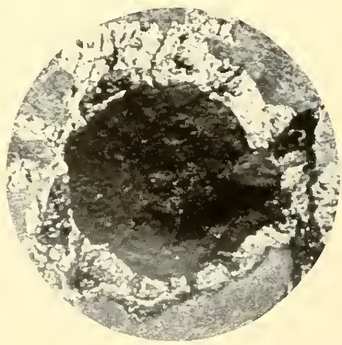


5

(1) Dendritic schreibersite in Arispe iron. (2) A polished and etched surface of the Mesa Verde iron. (3) Enlarged Widmanstätten figures showing arrangement of kamacite, taenite, and plessite. (4) A micro-section of the Estherville stony-iron. (5) A nodule of carbon with halo of schreibersite

ness the plates vary from the fraction of one to several millimeters, which fact forms the basis of their separation into *fine octahedrites* (Of), *medium octahedrites* (Om), and *coarse octahedrites* (Og), etc. (See under *Classification*, page 112.) At times the kamacite plates assume broad and irregular forms, as in the iron of Ainsworth and New Baltimore, which predominate over all other constituents

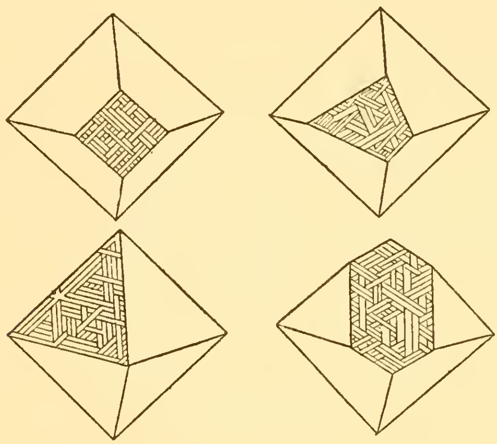


Fig. 7. Diagram showing Widmanstätten figures as appearing when an iron is cut at varying angles

and in which the octahedral structure is wholly undiscernible except on large surfaces.[3]

Not all irons show the octahedral structure. In some the alloys occur in the form of granules so fine as to escape easy notice and thus to appear of a noncrystalline structure, or, as we say, amorphous. These irons show on etching only certain faint parallel lines traversing the surface, which are due, according to Neumann, of Vienna, after whom they are named, to the union of crystals in

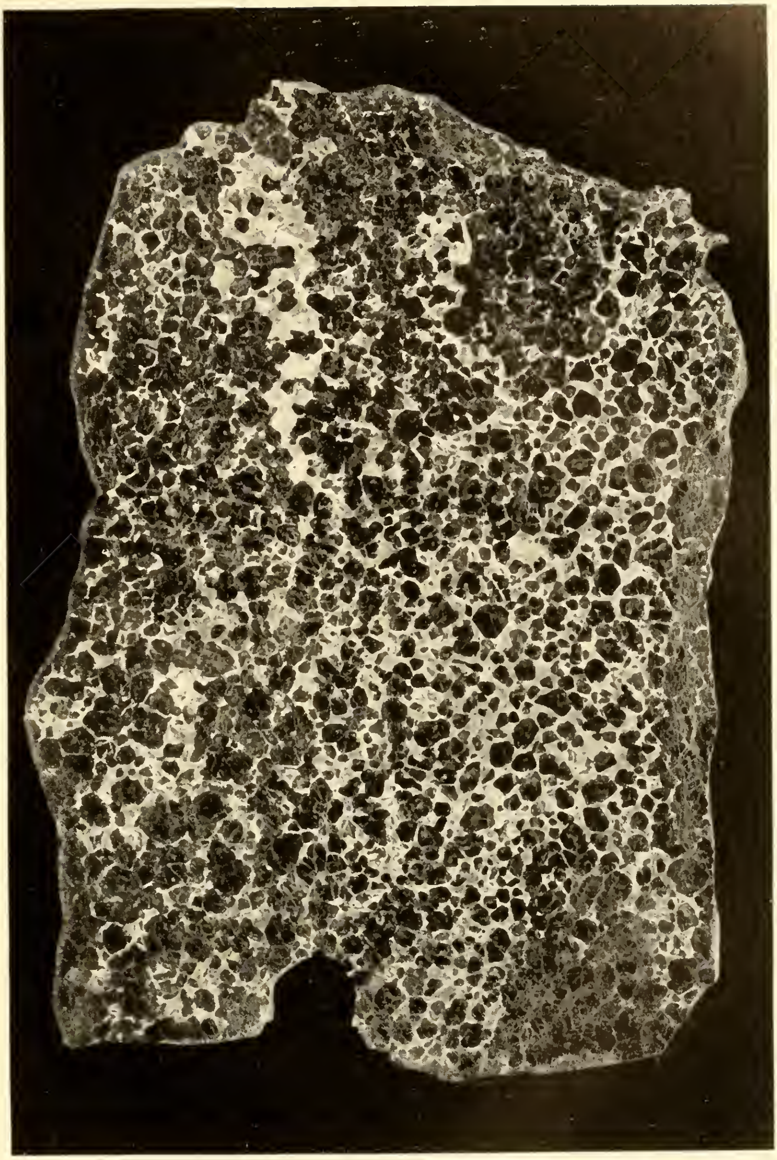
[3] Farrington's tabulation of analyses seems to show that the texture varies with the nickel content, the finest crystallization being found in irons richest in nickel. The ratio is, however, by no means constant. (*Field Museum Pub.* No. 120, 1907.)

definite opposed relations technically known as twinning, and in this case parallel with the faces of a cube (Plate 19, Figure 3). Still other irons are distinctly granular, a structure which, as shown later, may be due to the action of heat. The systematic regularity of arrangement of the taenite and kamacite plates which form the chief constituents of an iron is often interrupted by the presence in minor quantities of various accessory minerals, as cohenite, schreibersite, and troilite, or carbon nodules which are as a rule distributed without order or, it may be, in an octahedral iron, lying parallel with the kamacite bands. (Plate 20, Figures 1 and 5.)

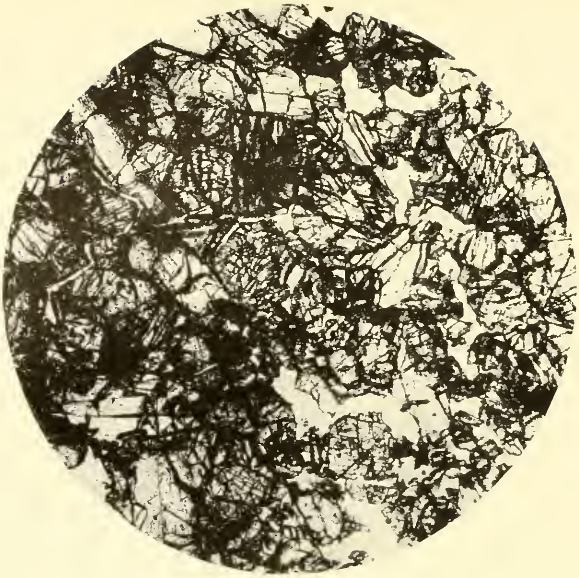
The interest of the structure is often enhanced by the diffusion of the mineral schreibersite in the so-called dendritic, or treelike forms, or as halos about nodular masses of graphite or carbon. Or, less strikingly, it may be disseminated in the form of plates or granules. The troilite occurs in granular irregular forms diffused through the iron, or in nodular masses admixed with carbon (see Plate 18) and at times in long thin lamellar forms lying parallel with the faces of a possible cube. These last forms were first recognized by Reichenbach and were named Reichenbachian lamellae by Tschermak. All these can be best understood by reference to figures in the plates.

2. Stony Iron Meteorites: Siderolites

Plate 21 is from a stony iron of the variety named pallasite after Peter Simon Pallas, a German naturalist whose famous scientific journey through Russia and Siberia under the patronage of the Empress Catherine II, on the occasion of the transit of Venus in 1769, formed the subject of a beautifully illustrated series of volumes which were translated into French and English. The specimen figured was found some years ago at a locality known as Mount Vernon, in Christian County, Ken-



A polished slice of the Mount Vernon, Kentucky, pallasite



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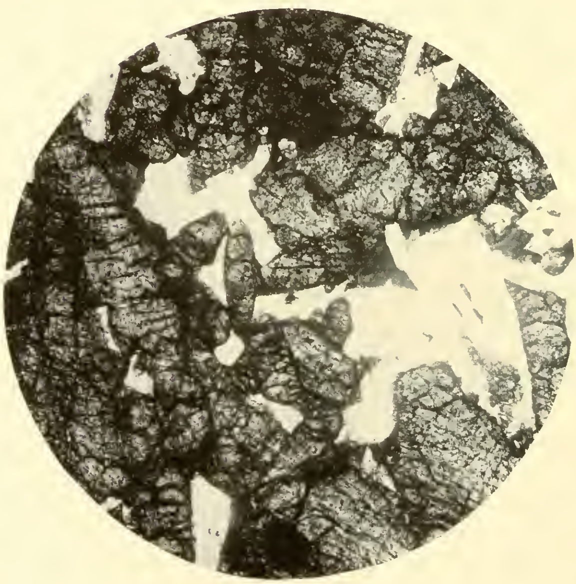


2

Figures showing the structure of the (1) El Nakhla and (2) Shergotty meteoric stones tucky. The light-colored netlike portion is composed of nickel-iron alloys identical in composition, so far as now ascertained, with those of the all-metal meteorites. The dark areas are silicate minerals—in this case olivine (peridotite). The structure has been compared, not inaptly, to that of a sponge in which the original sponge material is metal, the silicates filling the meshes. Meteorites of this type are somewhat rare, only about twenty now being known. It is to be noted that the metal, wherever surfaces of sufficient size are exposed, shows a tripartite structure and is never granular. Further, that the kamacite bands often surround the olivines in a form known as *swathing* kamacite, or white iron, on account of its color and brilliant reflection. Between the kamacite and plessite is often a thin band of taenite as in the all-metal forms.

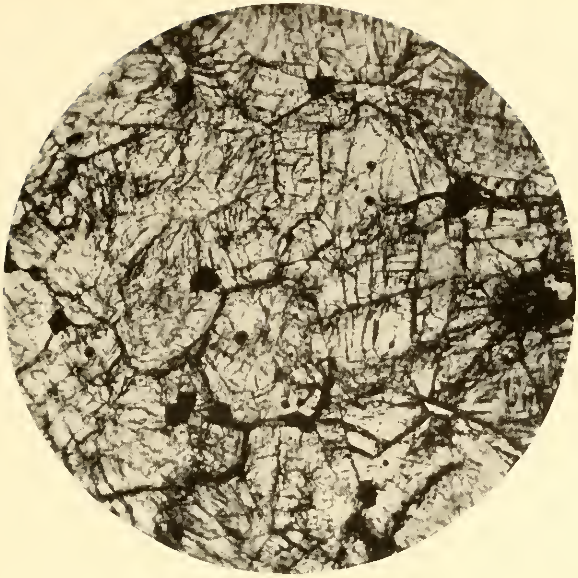
Interesting varietal phases of the pallasites are shown in Plate 19, Figure 1, where are aggregates of sharply angular silicate minerals imbedded in the metal like crushed stone in a cement floor. It is difficult in the present state of our knowledge to account for these forms excepting through pressure and shearing.

3. Stony Meteorites: Aerolites

The formulation of a satisfactory description of the internal structure of the stony meteorites is a matter of considerable difficulty, this in part owing to their confused and heterogeneous character. One might say that they were indescribable in words, at least in a manner that could be understood; hence recourse is made to ocular demonstration. For those unversed in modern methods of research it may be well to state that the methods pursued are essentially the same as with terrestrial rocks. A small fragment of the meteorite is ground smooth on one side and cemented with Canada balsam to a slip of glass, after which it is ground so thin as to be transparent, the slip of glass serving simply to hold the object while grinding and prevent its breaking. By means of an especially designed microscope it is then possible to determine the nature of the individual constituents and their arrangement one with another. The figures shown here are from photomicrographs made from these "thin sections" as they are called.

The one great difficulty in the determination and description of meteoric minerals lies in their imperfect crystalline development and shattered and often discolored condition caused by the oxidation of the lawrencite, troilite, and metallic portions. Many meteoric stones are plainly products of a somewhat hasty crystallization from a molten condition; few show the wholly crystalline structure due to gradual cooling, as in many terrestrial igneous rocks. Many, since cooling, have been shattered throughout from causes not yet wholly apparent, but probably by collision or rapid transitions from great heat to a corresponding cold. Still others are seemingly made up of recompacted dust and sand such as might result from the trituration of rock fragments in a volcanic throat, as happens in modern volcanoes, giving rise to a class of rocks known as *tuffs*. The individual particles may be of microscopic dimensions or in the form of recognizable fragments, as in Plate 17. The matter is further complicated by sundry changes, due to heat, which have taken place subsequent to this reconsolidation. Indeed the confused structure shown by many meteoric stones has given rise to an equal confusion on the part of students as to their causes.

Few meteoric stones, probably not over a score of those now known, show the crystalline structure characteristic of terrestrial igneous rocks, either basalts or peridotites. Such are best represented by the stones of Shergotty, India; El Nakhla, Egypt; and Chassigny, France; the first being much like a basalt, the second a pyroxenite and the third a peridotite. Still others are



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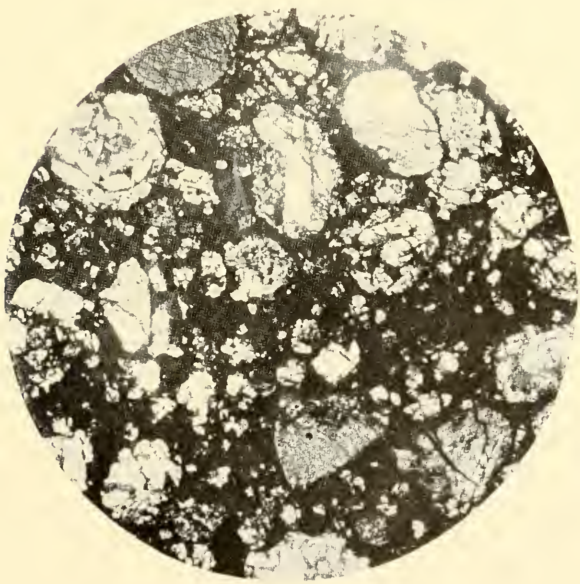


2

Figures showing the microstructure of the (1) Chassigny and (2) Selma meteoric stones

PLATE 24

1

2

3

Figures 1 and 2. Chondrules and chondroidal forms from the Bjurbole stone, and (3) a broken surface of the same stone showing chondritic structure made up of fragments of rocks, once crystalline, but broken up and recompacted. (Plates 22 and 23.)

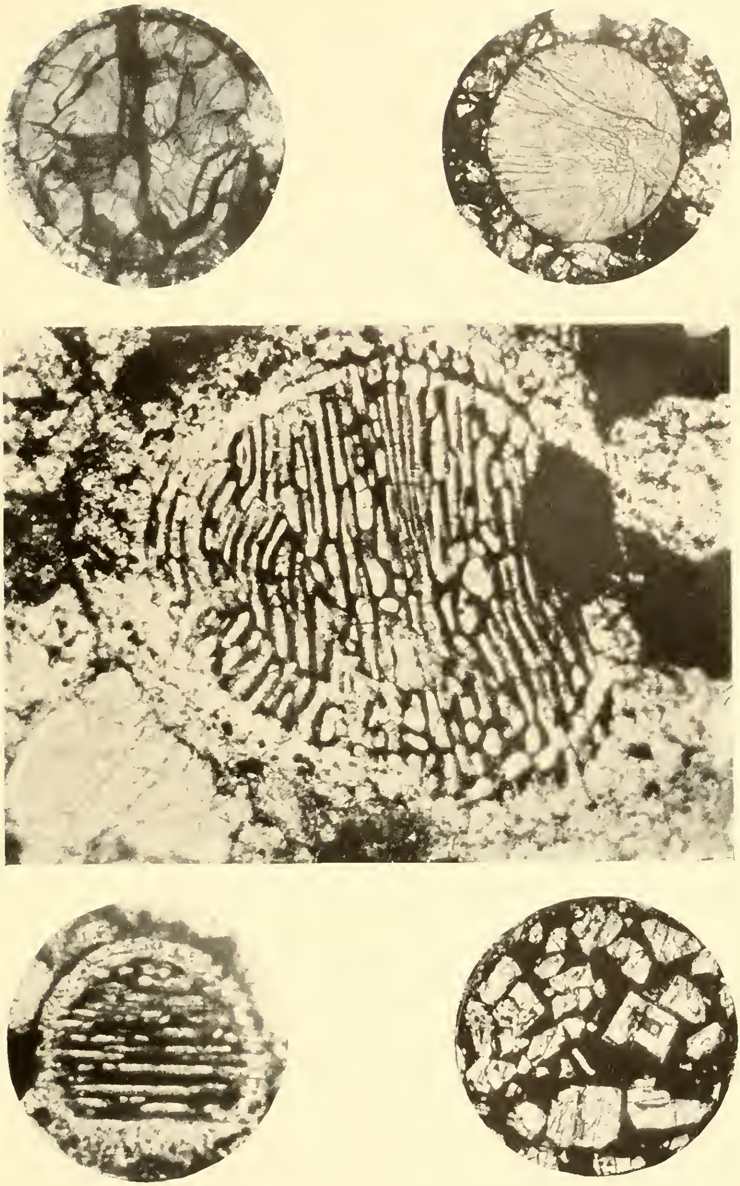
Fully ninety per cent of the known meteoric stones are made up of volcanic dust and sand as mentioned above and may be described as tuffaceous, or as tuffs. These are almost invariably characterized by the presence of small spherical, shotlike bodies called *chondrules* from a Greek word meaning *grain*, and the stones containing them *chondrites* for the same reason. This is a structure the exact counterpart of which has not been found in terrestrial rocks and the formation of which affords not only a distinctive characteristic, but in connection with their origin has been the cause of one of the most interesting and controversial questions relating to the subject in general. The structure of a typical chondritic meteorite, a *spherulitic chondrite* as it would be called, is shown on Plate 24. Stones of this type are often so friable as to be readily crushed, allowing the chondrules to become detached, as shown in Figures 1 and 2. In other cases they are held so firmly as to break with the matrix, when they appear in the thin section described above, as shown in Plates 25 and 26. Such interesting and peculiar forms are now known to be due to the cooling and partial crystallization of molten drops of stony matter; mineralogically they are mainly olivine and enstatite. Nevertheless, before their true nature was known, they were thought to be the remains of small organisms and were described as corals, crinoids, and problematic organisms. Their origin has been made the subject of much discussion and wordy warfare among students, but the matter need not be gone into further here. Those who have seen the Bessemer converter used in steel manufacture in operation, with the molten drops being blown from its mouth, will gain an idea of at least a possible method of their origin.

Occasional meteorites of this tuffaceous and chondritic type show signs of changes subsequent to their consolidation which are comparable to a form of metamorphism produced in terrestrial rocks by heat. This is due to a partial refusion of certain constituents. A discussion of these changes will, however, lead us too far astray for a work of this nature, so we may well stop here, with but a backward turning to the subject of meteoric irons. In Plate 27, Figure 1, is given a view of an etched surface of the iron of Toluca, Mexico, and in Figure 2 an etched surface of the same iron after it had been heated for some hours at a red heat in an ordinary coal fire. It will be noted that the characteristic octahedral structure has been partially obliterated by granulation. Berwerth, an Austrian worker who has carried on experiments in this line, states that by prolonged heating the octahedral structure can be made entirely to disappear and the iron to become granular throughout. This naturally brings up the question of the possibility that all the granular irons were once octahedral forms that have been changed by heating. Here again we get into too technical a phase of the subject and may stop with only a reference to the possibility that all the metal in stony meteorites may be secondary and due to the reduction of a ferrous chloride introduced in a liquid or gaseous condition subsequent to, or contemporaneous with the consolidation of the stone.

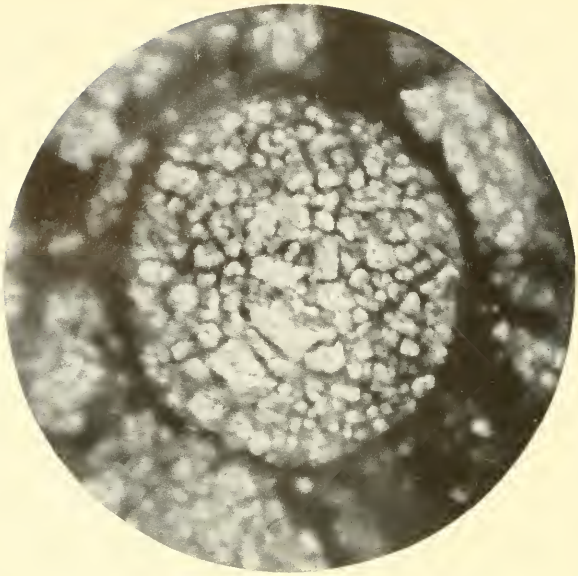
4. The Earth as a Meteorite

As long ago as 1848, the Frenchman, M. Boisse, pointed out the probable physical structure of a giant meteoric or cometary mass. He argued that, were one of these bodies brought into a condition of such fusion that the elements could group themselves according to their chemical affinities, the mass, on cooling, would assume a spherical form in which the constituents would be arranged according to their gradually decreasing densities. There would then be a metallic center, or core, of nickel-iron, surrounded by a zone of mixed ferruginous silicates and metal, and this in turn by zones of the lighter silicates,

PLATE 25



Five views of chondrules from various meteorites, as shown in thin sections



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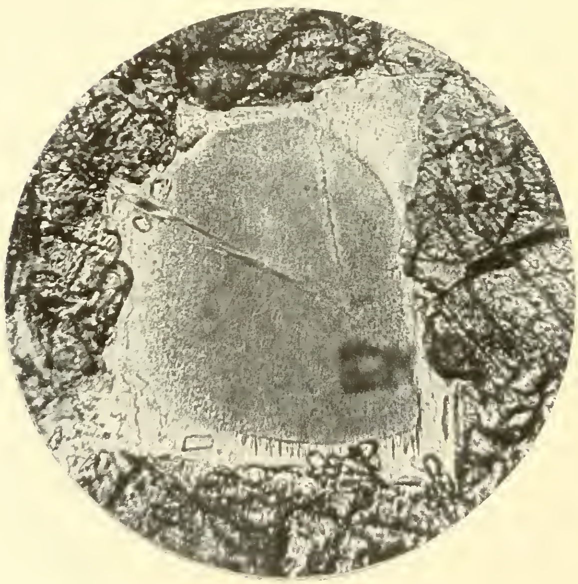


2

1. A chondrule in the Parnallee meteoric stone, showing a secondary glassy border. 2. Feldspar in the Estherville meteorite showing partial refusion

each grading into the next and becoming gradually metal-free. The same idea as to *earth* composition and structure has long been prevalent. Meunier, of Paris, elaborated it in 1867, and later Prior, of the British Museum, has given it a modern interpretation. According to the last-mentioned, the central earth core, while consisting essentially of nickel-iron, would carry also small quantities of unoxidized magnesium, calcium, sodium, aluminum, and chromium, with the nonmetals, silicon, sulphur, and carbon. Beyond this would be a zone in which these same elements occur, partly metallic and partly in the form of oxide compounds of magnesium, silicon, sodium, aluminum, and calcium (pyroxene, olivine, etc.), comparable to meteorites of the pallasite type. Beyond this again would be still other zones, of gradually decreasing densities, composed of the highly oxidized and less ferriferous silicates, comparable with the stony meteorites or aerolites, ultimately passing into rocks of the basaltic type, from which, through weathering, decomposition, and complex metamorphism, have been derived those forming the present surface features.[4] The subject offers an interesting field of speculation, but is quite beyond our field of discussion, unless one chooses to go to the extreme of considering the earth itself a giant meteorite.

"Il n'est pas malaise d'inférer de tout ceci que la Terre et les cieux sont faits d'une mème matière." [5]

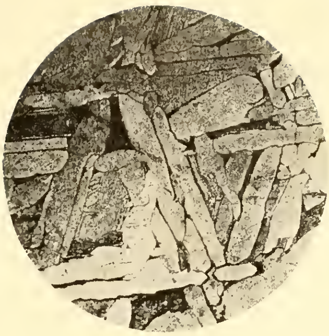
We should like, with Arrhenius, to think of a world new-born and barren, to which the seeds of life might be borne by a swift-flying meteor; a life which, however humble in its beginning, might develop through countless years into forms as high and perhaps even higher than our own. Fascinating as such a thought may be, how-

[4] V. M. Goldschmidt, and later Adams and Washington (*Zeit. Elektrochem.*, Vol. 28, 1922, and *J. Washington Acad. Sci.*, Vol. 14, No. 14, 1924) have discussed the matter with very like conclusions.

[5] Descartes, quoted by Daubrée.

ever, it is based upon but flimsy foundations. Not only are our meteorites of materials little likely to contain possible animate matter, but the very conditions through which they pass, from the cold of space to the fiery proximity of the sun and the final scorching plunge into an atmosphere like ours, are all against the survival of organic life even if it once existed.

PLATE 27



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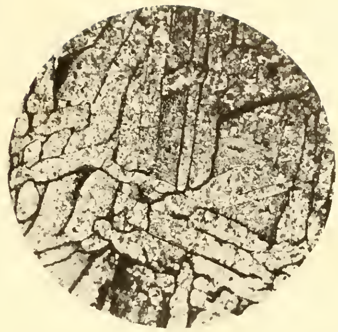

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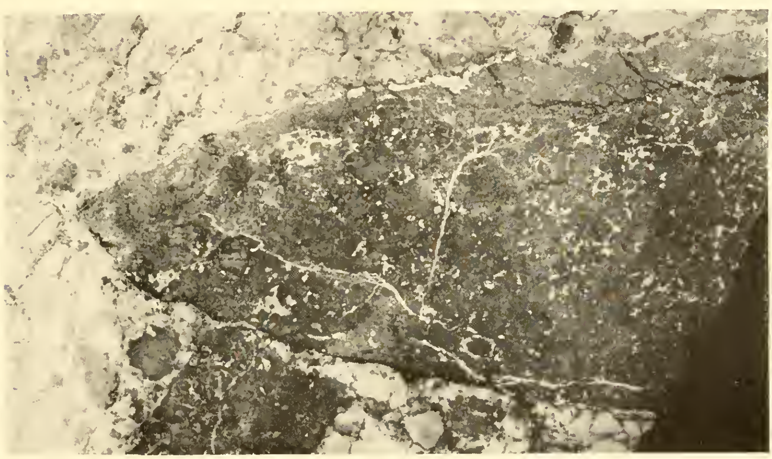

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Two figures showing the structure of the Toluca meteoric iron, before and after heating, and (3) a polished surface of the Cumberland Falls meteoric stone showing the distribution of the iron

CHAPTER VI

NAMES AND CLASSIFICATION

What's in a name? Apparently not much in the mind of him who raised the question. But conditions alter cases. Sometimes much depends on the name. It furnishes at least a handle by which to take hold—something to fix in mind that which one is writing or talking about.

In the early days, before their nature was fully understood, various names were given to meteorites, based upon conditions attendant upon their falling or other natural causes, regardless of their mineral nature. *Shooting stars*, *bolides*, *fireballs*, *thunderstones*, *uranolites*, and *skystones* are among the more common, and of which each language furnished its own equivalent. The term *aerolite* is stated to have been applied by Blumenbach as early as 1804, and the distinction between stones and irons was likewise early made apparent in the nomenclature. It was not until 1863 that Prof. H. Story Maskelyne made the present accepted division into (1) aerolites, (2) aerosiderolites, and (3) aerosiderites, names now generally shortened into aerolites, siderolites, and siderites, designating the stony meteorites, stony-iron meteorites, and iron meteorites, respectively. Gustav Rose in 1862 made the suggestion, now generally adopted, that the finer subdivisions of meteoric stones be based upon mineral composition and structure; and divided them into chondrites and achondrites accordingly as they did or did not carry the peculiar rounded bodies known to the Germans as *Kugeln*, but to the English as chondrules. From these early beginnings has been evolved what is called the Rose-Tschermak-Brezina classification here tabulated. The French authority, Meunier, also evolved a scheme which has, however, failed of so general an adoption by European and American workers.

Meteorites are named after the locality where they fall or are found, as *Allegan*, *Bustee*, *Weston*, etc., each of which represents a post office or other geographic subdivision of sufficient importance to be found on any detailed geographic map or comprehensive gazetteer.

At first thought this system may seem inexact and unscientific. As a matter of fact it has been found to work well in practical application, and leads to little confusion. The old saying that "lightning never strikes twice in the same place" may with equal proximity to accuracy be said of meteorites, no two falls being recorded from the same area. The main objection to the system thus far developed lies in the wide extent of certain falls, as that of Estherville, Iowa, and occasionally the lack of a precise geographic name, as in regions remote from human settlement.[1] In such cases the latitude and longitude are, or should, always be given, together with the nearest named locality. The advisability of a geographic and also a time record, in case of an observed fall, lies in the necessity for data in the study of the probable ultra-terrestrial source from which the meteorite may have come.

In classifying meteorites, recognition, as stated, is given mainly to the internal structure and mineral composition. Obviously mode of occurrence and source can not be given consideration as among terrestrial rocks.

[1] A good illustration of this is offered by the so-called Four Corners meteorite. The gazetteer and post-office directory recognize no such locality. But the iron was found in New Mexico near the intersection of the boundary line of Arizona, Colorado, New Mexico, and Utah. There is no similar instance in the country, and the same is felt to be sufficiently distinctive. All attempts at naming meteorites after individuals—at "creating a progeny for the childless," as is done in mineralogy and biology—have failed. The workers will not accept them.

Chemically all belong to the basic divisions of terrestrial rocks and would fall within the basalt-pyroxenite-peridotite series. The attempt recently made to classify the stony meteorites under the "quantitative system" of the modern petrographers cannot be considered satisfactory, since it is based wholly upon chemical analyses and resultant theoretic mineral composition. The two systems which have met with most widespread acceptance are those gradually evolved from the work of Rose, Tschermak, and Brezina, already mentioned, and of S. Meunier. In both systems the three primary subdivisions already noted are based upon the relative preponderance of the stony and metallic constituents. These are again subdivided according to the chemical nature of the prevailing silicates and their structure. The main divisions are:

Aerolites or stony meteorites	Consisting essentially of silicate minerals with minor amounts of the metallic alloys and sulphides.
Siderolites or stony-iron meteorites	Consisting of an extremely variable network or sponge of metal, the interstices of which are occupied by the silicate minerals.
Siderites or iron meteorites	Consisting essentially of an alloy of nickel-iron with iron phosphides and sulphides.

The detailed classification will be found in Appendix I.

CHAPTER VII

WHENCE DO THEY COME?

We come now to the question of the ultimate source and origin of these interesting and remarkable bodies. Naturally the striking character of the phenomenon of a falling meteor would serve to excite the dullest imagination, while the range of seeming possibilities is so great as to tempt flights from the known far into the unknown, even into realms where the wildest imagery can be freely indulged without fear of disastrous collision with solid fact.

The problem is largely an astronomical one, as may be readily understood, as may also the fact of its difficult solution. Observations of individual meteors are numerous, but are necessarily of such brief duration as to render them in most cases of doubtful value. That portion of our information for which we may claim approximate certainty is that relating only to the closing chapter in what may be called the life history of a meteorite. We may theorize over the ultimate source, and even on the origin of matter itself; from observations of speed and orbit, we may gain an approximate idea of the portion of space whence it was derived; but only in the meteorite itself do we have a tangible actuality which may be studied at leisure.

Let us consider in an historical way some of the more plausible of the theories thus far advanced. The path to solution may seem at times blind and devious, but leads nevertheless toward a clear understanding of the matter.

First, as an example of the numerous theories—flights of the imagination I could almost call them—let me quote from a summary of them by Professor Newton:

> They came from the moon; they came from the earth's volcanoes; they came from the sun; they came from Jupiter and the other planets; they came from some destroyed planet; they came from comets; they came from the nebulous mass from which the solar system has grown; they came from the fixed stars; they came from the depths of space.

Fortunately not all of these suggestions are of sufficient probability to merit attention today.

It was Chladni who, more than a hundred years ago, advanced the idea that meteorites are but the remnants of cosmic matter employed in the formation of worlds. He looked upon comets, falling stars, meteoric fireballs, and meteorites as all of a similar elementary constitution and origin. Though more recent students may be inclined to regard his conclusions as a series of lucky guesses, the fact remains that subsequent investigation has shown him to have been essentially correct in many of them. If, however, worlds like ours, as we know it, have been formed from meteoric aggregates, we must conclude that the meteorites of the past, while, it may be, composed of the same kind of elementary matter, held it in quite different proportions, since the most abundant of known world materials are, as has been shown, among the least abundant of meteoric substances.

Astronomers tell us that in the far reaches of space beyond our solar system are dark nebulous clouds which obscure the more distant stars, as nearer stars are obscured by thin clouds of vapor. What may be the nature of these clouds is wholly speculative. That they are not water vapor and have nothing to do with our atmosphere is certain. May we not with a fair degree of assurance assume that they are composed of fragmental—discrete—matter like the ejectamenta of a modern volcano, and that in time this will be gathered in as meteoric matter by neighboring planets? With the aftermath of sunglows caused by dust from Krakatoa in mind, this should subject a facile imagination to no serious strain, and a world free-floating and slowly augmenting its bulk through the ingathering of waste from space is a fascinating vision. From such a conception we are somewhat rudely awakened by Chamberlin who now considers the idea that planets have been formed by infalls of scattered meteorites as "an old and practically abandoned theory."[1]

Wilhelm Olbers, another of the early workers, considered for a time (1795) the possibility of meteorites having been ejected from lunar volcanoes.[2] This view was accepted by Lichtenberg, who remarked incidentally that "the moon was an uncivil neighbor for throwing stones at us." No less an authority than Laplace gave it favorable consideration.[3] As the attraction of gravity at the surface of the moon is much less, only about one-sixth that of the earth, and as it has no atmosphere, it was conceived possible that by explosive volcanic action a body might be so far projected into space as to pass quite beyond gravimetric recall and become a satellite of the earth, about which it would revolve in a more or less elongated orbit until, its speed sufficiently retarded, it would fall with all the attendant phenomena of a meteorite. This view, with various modifications, has been adopted by several of the more recent workers, among whom mention should be made of J. Lawrence Smith who wrote as late as 1885, and with pleasing certainty: "There is not a single evidence of the identity of shooting stars (as exemplified in the periodical meteors of August and November) and those meteors which give rise to meteoric stones." He argued that all meteoric masses had a common origin and at one time formed parts of some large body; that all had been subjected to more

[1] The genesis of planets. *Yearbook Carnegie Institution*, 1924, p. 273.

[2] According to Phipson this idea was first put forward by Paolo Maria Terzazo in 1664.

[3] "It is not impossible that large masses detached from some of the celestial bodies, and particularly from the moon, may have sometimes been projected to the earth." (Laplace, quoted with approval by Olbers, *Tilloch's Magazine*, May, 1803.)

PLATE 28

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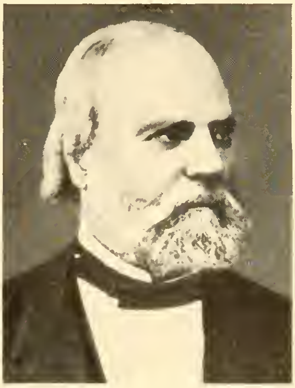

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(1) F. Berwerth; (2) J. L. Smith; (3) H. C. Sorby;
(4) C. U. Shepard

or less prolonged igneous action, corresponding to that of terrestrial volcanoes, and that they possessed the average specific gravity of the moon. His conclusions at this date he summed up as follows:

> It may be stated that the moon is the only large body in space of which we have knowledge possessing the requisite conditions demanded by the physical and chemical properties of meteorites. They have been thrown off by volcanic action or some other disruptive force and encountering no gaseous medium of resistance have reached such a distance that it no longer exercises a preponderating attraction. The deported fragments, having in common with the moon itself an orbital velocity now more or less modified by the projectile force and new conditions of attraction in which they have been placed with reference to the earth, acquire an independent orbit more or less elliptical. This orbit, subject to great disturbing influences, sooner or later passes through our atmosphere, and the flying fragments are intercepted by the body of the globe.

Thus plainly and seemingly conclusively the problem was solved.

Plausible as these views may have seemed at the time, it has been contended by others that it is impossible that a body the size of the moon could contain volcanoes of sufficient projective power to produce these results; and, further, it was shown in 1859, by the calculations of B. A. Gould, that even were bodies thus thrown out, there is not one chance in two million that one of them would ever reach the earth as an aerolite.

In 1811, the astronomer Olbers, whose transient views have been mentioned, came forward with a new suggestion which for some years received favorable consideration. He regarded the asteroids Ceres, Juno, Pallas, and Vesta, as the principal remains of a large planet revolving between Mars and Jupiter, which had burst into fragments through some internal (and unaccountable) explosion. The smaller of these fragments he thought to have continued their revolutions about the sun, in an eccentric orbit, until, coming within the attractive limits of the earth, they were precipitated as meteorites. As the astronomer Young has stated, granted the explosion,[4] there is nothing improbable in the hypothesis.

H. C. Sorby, from a study of the microscopic structure of stony meteorites, was led to consider it extremely improbable that they were derived from the moon or a planet which differs from a large meteorite in having been the seat of more or less modified volcanic action. His views, it will be observed, had more to do with *conditions* than with actual source. He believed that the constituents of meteorites were originally in a state of vapor such as now exists in the atmosphere of the sun. This, on cooling, condensed into a sort of cometary cloud formed of small crystals and minute drops of melted stony matter which afterwards became more or less crystalline. This cloud being in a state of great commotion, the particles moving with great velocity were often broken by collisions among themselves. The particles thus formed were subsequently collected into larger masses and by heat of impact underwent a more or less complete metamorphism whereby their original nature became quite obscured.[5] In the meantime, the metallic constituents were introduced in a state of vapor and condensed in the interstices of the silicates, as we now find them. The occasional presence of hydrocarbons was thought to be due to a condensation of vapors at a later period.[6] "I therefore conclude," he wrote, "provisionally, that meteorites are records of the existence in planetary space of physical conditions more or less similar to those now confined to the immediate neighborhood of the sun, at a period indefinitely more remote than that of the occurrence of any of the facts revealed to us by the study of geology—at a

[4] That such an explosion is possible seems to be shown by recent observations on the star Nova Poctoris in 1925.

[5] See also under origin of chondritic structure, page 75.

[6] It has since been shown that the presence of hydrocarbons in meteorites is very doubtful.

period which might in fact be called preterrestrial." It may be inferred from this that he regarded their source as interplanetary.

Prof. C. U. Shepard, one-time assistant chemist at Yale University, and one of the most enthusiastic of American students and collectors of meteorites, inclined to the belief that the material of which they are composed was of terrestrial origin; that it had been, while in a gaseous condition, blown by explosive volcanic action beyond the limits of our atmosphere, where it was sustained by magneto-electric forces; and that a meteorite fall was as much to be expected from a disturbance of these forces as would be a shower of rain from similar causes. Wastman, as quoted by Galloway,[7] makes a like lucid (?) suggestion. "The meteors probably owe their origin to the disengagement of electricity or some analogous matter, which takes place in the celestial regions on every occasion in which the conditions necessary for the production of the phenomena are renewed." Shepard's view was not generally accepted, though the idea that the explosive force so frequently mentioned might have been volcanic and in the nature of a terrestrial volcano, as often suggested, was firmly adhered to as late as 1883 by the French astronomer, C. Flammarion. "The greater part of the stones that fall from the heavens were originally of the earth and have been thrown into space by volcanic eruptions in primitive times," he wrote.[8]

Stanislas Meunier, of the Paris Museum of Natural History, and a prominent student of meteorites, also inclined to the belief that meteorites were formed under conditions similar to those which have existed in the past upon our earth; but that those now coming to us are from a one-time existing satellite, smaller than the moon, which, having already passed through the stages of planetary evolution, has been resolved into fragments which

[7] *Edinburg New Philos. Journ.*, Vol. 30, 1841.

[8] L'Astronomie, Vol. 2, 1883, p. 141.

are gradually falling back once more upon the body from which they were originally derived.

A. Daubrée, at one time a most eminent authority on the constitution of meteorites, was disposed, with Olbers, to regard them as products of the disintegration of asteroids, as the result of an explosion, or more commonly of a violent shock, as a collision. "The meteorites which fall upon our planet," he wrote, "illustrate one of the changes which are going on in space through the distribution of the '*débris* of demolition' of certain stars or asteriods among other stars."

The Austrian, Gustav Tschermak, than whom there were few better authorities concerning composition and structure, writing in 1875, called attention to the fact that the form of meteorites "is likely to afford some insight as regards the antecedents of the masses whence they are derived." He agreed with the German, Haidinger, that each meteorite as it enters our atmosphere is a fragment and owes its form to a disruption of a larger mass, although he did not lose sight of the fact that many meteorites are broken further by the resistance of the atmosphere during their fall. Briefly stated, he concluded that "it would then appear that the material of which meteorites consist has been furnished by one or more large masses, the formation of which must have occupied a long period of time."

With Daubrée's idea of disintegration by impact (*i.e.*, collision) Tschermak did not agree but thought it much more probable that, to whatever degree such disintegration had been carried, it had been brought about by a force acting from within outward—in short, by an explosion. In other words, he seemed to regard the evidence of volcanic activity found in the tuffaceous and chondritic structure of a meteorite proof of explosive force sufficient to account for the gradual destruction of the original body, whatever its nature or mass. Berwerth,

PLATE 29

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(1) S. Meunier; (2) A. Daubrée; (3) G. Tschermak;
(4) D. Olmsted

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(1) H. A. Newton; (2) Norman Lockyer

likewise of Vienna, writing as late as 1907,[9] favored the explosive hypothesis. He felt that all the circumstances point to successive explosions from a celestial body of considerable size but not of sufficient gravimetric attractive power to draw back to itself the ejected fragments. Through these successive explosions the body itself would become more or less completely resolved into fragments that now, in various routes, are traversing space.

Among the recent speculations relative to the origin of meteorites, mention must be made of those of Prof. T. C. Chamberlin and Prof. W. H. Pickering. The first named, considering their origin through the disruption of small planetary bodies, suggests that the fragmentation may have been brought about without actual collisions between themselves, but by the disrupting action of attraction when two bodies of sufficient mass and density come near to one another, *i.e.*, within the "Roche limit," as it is called. Bodies thus disrupted, so long as their fragments remained clustered, would form comets, but when dispersed by approach to another body of sufficient attractive force, might constitute meteorites. Professor Pickering suggests that, as an alternative hypothesis, the stony meteorites may be considered as formed "during the great cataclasm that occurred at the time the moon separated from the earth." That when the pressure on the deep-lying portions of the earth was suddenly relieved through the flying off of the upper layers, now forming the moon, considerable portions of our atmosphere must have followed the larger flying masses, which would so retard the smaller that they in part failed to escape the attractive power of the earth. These, flying in constantly shifting orbits due to perturbations caused by proximity of the earth and moon, would ultimately pass near enough to one of these bodies to be torn to pieces, in the manner suggested by Chamberlin, and ultimately find their way back to earth as meteorites.

[9] *Sitz. der Kais. Akad. der Wiss.*, Bd. cxvi, Abt. ii, 1907.

Here, it will be observed, is a theory based upon a by no means commonly accepted hypothesis.

Almost as a matter of course there was from very early times a supposed direct connection between the meteorites which come so noisily to earth, and the silent, seemingly intangible meteors or shooting stars of the periodic showers. Denison Olmsted of Yale (in 1834) was among the first to raise an apparently well-formed doubt as to this identity. He based these doubts on the lack of apparent time relation between meteor displays and meteorite falls, and in part on the apparently easily combustible nature of the periodic meteors, some of them being thought of a flocculent nature and of the texture of cotton, and even of matter so attenuated as to be almost impalpable. Olmsted, too, was the first to call attention to the fact that the November meteors all emanated from a common visual center, having a focus, since called the radiant point, which is situated in the constellation of Leo. The August meteors, on the other hand, have their radiant in the constellation of Perseus, and those of April in that of Lyra. In the last two cases, it should be mentioned, the radiant points are not stationary, but in rapid motion.[10]

Olmsted's doubts as to the identity of meteors and meteorites were not shared wholly by either his contemporaries or those who came after. Daniel Kirkwood, in his work on *Meteoric Astronomy* (1807), while acknowledging that "no deposits from ordinary shooting stars have been known to reach the earth's surface,"[11] yet believed the two classes of bodies to be coexistent, "that meteoric

[10] The Italian astronomer Schiaparelli calculated that the meteoric stone of Pultusk, which fell on January 30, 1868, came from the constellation of the Great Bear, while that of Knyahinya, which fell June 9, 1866, was from Pisces.

[11] It is to be noted, however, that of the seventeen irons that have been seen to fall, there are two, those of Rowton (1876) and Mazapil (1885), which can be thus relegated, the first with the Lyrid meteors and the second with the Andromedes. In consideration of the known fairly uniform distribution of meteorite falls throughout the year, such can be considered little more than coincidences. (See also page 95.)

stones are but the largest masses in nebulous rings from which showers of shooting stars are derived."

In a lecture delivered at the Sheffield Scientific School of Yale University in 1879, Prof. H. L. Newton, after a review of the general subject, stated:

> Thus we are led to say: First, that the periodic meteors of November, of August, or April, etc., are caused by solid fragments of certain known or unknown comets coming into our air; secondly, that the sporadic meteors such as we can see any clear night are the like fragments of other comets; thirdly, that the large fireballs are only larger fragments of the same kind; and finally, that this stone [a fragment of the Homestead fall of 1879] which was broken off one of those large fragments in coming through our air, must once have been a part of a comet. [12]

And again, in his address before the American Association for the Advancement of Science in 1886, he stated that

> We may reasonably believe that the bodies that cause the shooting stars, the large fireballs, and the stone-producing meteors, all belong to one class; they differ in kind of material, in density, in size, but from the faintest shooting star to the largest stone meteor we pass by such small gradations that no clear dividing lines can separate them into classes.

Essentially the same views are given by Lockyer in his *Meteoritic Hypothesis* (1890) and are very generally adopted. As confirmatory of this hypothetical source, reference is commonly made to the history of Biela's comet. This was first seen in March, 1772, when it was found to be traveling in an eccentric orbit about the sun, including in its course a portion of the orbit of the earth. Since its first discovery and during the residual period of its existence, it has made this journey every 6⅔ years. The last seen of it in its primary condition was in 1832. When it became due in 1839 it was on the opposite side of the sun from the earth and hence invisible. In 1845 it

[12] "All the solar space," writes Olivier, "must be populated by *débris* of comets long since broken up into tiny fragments of their original great volume." (Meteors, 1925, p. 23.)

became visible again, but was broken into two widely separated portions, each with a train of its own. In 1852 it appeared for the last time as a comet, and in 1859, when its return was looked for, there was found but an enormous train of meteors.[13]

The career of Biela's comet is now very generally assumed to be common to every cometary body, and whenever there are seen numerous shooting stars darting rocketlike across our sky, it is thought that our earth, in its journey through space, is crossing the trail of one of these seemingly erratic bodies. The meteoric iron which fell at Mazapil, Mexico, on November 27, 1885, is considered by some as a fragment of the Biela comet.

Seemingly this should be conclusive, but it is not. It appears that the velocity with which *some* meteorites penetrate our atmosphere is too great to allow of their being considered as belonging to our solar system, as do the comets. They are interstellar rather than interplanetary. The Italian astronomer, Schiaparelli, was inclined on this account to regard the large meteorites as coming from sources outside of our system, and Olivier writes: "We have positive proof that many meteorites come from interstellar space, while all comets seem to belong to our system." So far as I am aware, but one writer—Pickering—has ventured the suggestion—and it is but a venture—that there may be a difference in kind in the meteorites from near and distant sources.[14]

Do meteorites of like nature have a common origin? The

[13] Five or more well-known comets have completely disappeared, and the meteors in each group are distributed along the orbit of their maternal ancestor.

[14] The theory of Professor Stroemgren of Denmark, as noted in *Science News* (*Science*, January 19, 1923) maintains:

"That all comets originally traveled in elliptical or closed orbits, periodically coming closer to the sun from the outer regions of the planetary system. It maintains that the material composing comets is a part of the original nebula out of which the sun and his family are thought to have formed. According to this theory, the disturbing influences of the planets have changed the orbits of some comets from the closed-path to the open form. That is, the perturbations by the planets have resulted in throwing some of the original material of the solar system off of its beaten track and out into the emptiness of interstellar space, never to return."

PLATE 31

Biela's comet before and after division. (From *Knowledge*, Dec. 16, 1881)

most systematic investigations made of late years with reference to the possible identity of source of meteorites of like chemical and mineralogical nature are those of A. G. Högbom,[15] of Upsala, and F. Berwerth, of Vienna. Through means of a graphic chart upon which he has tabulated all known falls according to the day, month, and year, and differentiated the kinds each by a special symbol, the first-named has shown that the meteorites have a somewhat irregular distribution, so that a single day or group of days may show many falls, while on intervening days there are none. The question arose if this irregularity could be explained on the ground that the falls belonging to the same or closely neighboring days of successive years may come from the same source—may originate from a swarm of meteors which many times but at regular periods has crossed the earth's path. The suggestion is particularly pertinent when the kind of meteorite is considered. Thus it is shown that of the group of howardites, of which but nine falls were then known, three fell during the first weeks of August, and three others in the first half of December. With the December howardites there occur a bustite, a chladnite, and a howarditic chrondrite, all closely related forms. Around the first of October is shown a chassignite, two howarditic chrondrites, and a howardite. A like association occurs also at the end of March. Still another type, that of the eukrites, was at time of writing represented by three falls the dates of which were known, two of which occurred in June, the 13th and 15th respectively; the third on May 22. A fourth fell on June 28, 1911.

Recent falls do not, however, in all cases support these apparent conclusions, as is shown in the following table which includes two additional falls of howardites since the appearance of Professor Högbom's paper. As a matter of additional interest, the original weights, so far as known, and that of each now preserved, are also given.

[15] *Bull. Geol. Inst. Univ. Upsala*, Vol. 5, 1900-1901, p. 132.

HOWARDITES

Locality of Fall	Date of Fall	Original Wt.	Known Wt.
Massing, Germany.....	Dec. 13, 1803	1.6 kg.	74 gr.
Loutolax, Finland......	Dec. 13, 1813	?	894 gr.
Nobleboro, U. S. A.....	Aug. 7, 1823	1.80–2.75 kg.	78 gr.
Bialystok, Poland......	Oct. 5, 1827	4.0 kg.	627 gr.
La Vivionerre, France..	July 14, 1845	780 gr.	799 gr.
Petersburg, U. S. A....	Aug. 5, 1855	1764 gr.	399 gr.
Zmenj, Russia.........	Aug. ?, 1858	246 gr.	155 gr.
Frankfort, U. S. A.....	Dec. 5, 1868	650 gr.	535 gr.
Yodze, Russia.........	June 17, 1877	?	43 gr.
Pawlovka, Russia......	Aug. 2, 1882	2.0 kg.	1123 gr.
Bholghati, India.......	Oct. 29, 1905	2.0 kg.	1028 gr.
Simondium, S. Africa...	?	?	1000 gr.

Disregarding Simondium, but including Zmenj, of which the day of the month is unknown, it appears that one has fallen in June, one in July, four in August, two in October, and three in December.

The group of chladnites would, on account of their distinctive character, seem favorable to calculations of this nature, but these, too, fail to yield definite results, as seen below.

CHLADNITES

Name	Date of Fall
Manegaon, India..............................	June 29, 1843
Bishopville, U. S. A..........................	Mar. 29, 1843
Shalka, India................................	Nov. 30, 1850
Ibbenbuhren, Germany.......................	June 17, 1870
Cumberland Falls, U. S. A....................	Apr. 9, 1919
Johnstown, U. S. A...........................	July 5, 1924

Berwerth[16] followed out the same line of thought, utilizing the same data but grouping them in a slightly

[16] *Sitz. der Kais. Akad. der Wiss.*, Bd. cxvi, Abt. ii, 1907.

different manner, and reached conclusions quite similar to those of Högbom. He regards the meteoric streams as originating through the throwing off of particles from some of the smaller heavenly bodies, each such stream possessing its own degree of homogeneity but differing from that of another stream. When there is an intersection of the orbits of the earth and these streams, each may leave its own characteristic record of meteoric matter. He finds, for instance, as did Högbom and Tschermak, the stones of the class of eukrites offering the most conclusive evidence of such conditions. The same reservations apply in this case as in that above. Here, as in many another theory, more observations are needed before conclusions can be reached.[17]

In this connection the following table compiled by Dr. Peter Tscherwinsky[18] is of interest. It shows the total number of observed falls, grouped by months.

January....	30	May.......	50	September..	34
February...	26	June.......	51	October....	29
March.....	22	July.......	40	November..	30
April......	43	August.....	40	December..	27
				Total....	422

From this it is readily apparent that the greatest number of actually observed falls occur in May and June, a fact which does not accord with the idea that their source is that of the periodic showers.

As having a possible bearing upon the subject, the following calculations were made by Merrill,[19] showing the percentage number of falls and finds with reference to their varying basicity:

Of the total 367 known meteoric irons there were seen to

[17] It may be added that Professor Haskins, of Chicago, has recently compared the chlorine of meteorites with that of terrestrial minerals, with reference to its isotopes and atomic weights, and finds them identical. He regards this as indicative of a common origin—the sun—for the two bodies.

[18] *Centralblatt fur Min., Geol., etc.*, No. 7, 1926, p. 239.

[19] *Proc. Nat. Acad. Sci.*, Vol. 5, 1919, pp. 37-39.

fall but seventeen, or less than five per cent. These are essentially metallic; ultra basic.

Of the thirty-one known stony irons variously classed as lodranites, pallasites, and mesosiderites, carrying at times as high as fifty per cent metal, there were seen to fall but five, or, in round numbers, sixteen per cent.

Of the 370 known stones composed mainly of silicate minerals, with chondritic structure, carrying from five to twenty-five per cent metal (howarditic chondrites to ureilites inclusive), there were seen to fall 322, or eighty-seven per cent.

Of the twenty-one calcium-aluminum-rich stones, carrying less than one per cent metal, free of chondrules, and variously classed as angrites, eukrites, shergottites, and howardites, there were seen to fall twenty, or ninety-five per cent.

Of the twelve magnesia-rich stones essentially free from metal, without chondrules, and classed as bustites, chassignites, chladnites, and amphoterites, the most acidic types known, there were seen to fall twelve, or one hundred per cent.

The suggestion is made, though not emphasized, that there is indicated a gradually increasing acidity of the incoming material as time goes on, and reference also made to the possibility that meteors of present-day showers may be of an easily combustible nature, and hence consumed before reaching the earth.

It has been shown that the number of meteors observed between the hours of midnight and 6 a.m. was larger than for any corresponding period of the day. That there is a discrepancy between this record and that of actual falls was pointed out in 1861 by Haidinger whose record of 126 observed falls shows a slight excess in the number falling in the afternoon, the hours from noon to 9 p. m. being particularly prolific. O. C. Farrington has recently made a new compilation from data now available and shows that out of 273 falls, the records of which are fairly satisfactory, 184 occurred between noon and midnight and but eighty-nine between midnight and noon. Such a discrepancy may be accounted for in part by the possible difference in quantity and kind of material, and in part by the direction of travel and the consequent heat generated in passage.

In the following table is given the number of annually recorded falls, the authenticity of which has been placed beyond question through the finding and preservation of at least a portion of the material. That the numbers given are below those of the actual falls is almost self-evident, many not having been seen, and many that were seen not recorded.

Annual Falls of Meteorites Since 1880

Year	No.	Year	No.
1880	3	1903	6
1881	2	1904	3
1882	4	1905	4
1883	3	1906	2
1884	3	1907	3
1885	4	1908	3
1886	7	1909	3
1887	6	1910	7
1888	0	1911	3
1889	5	1912	3
1890	6	1913	1
1891	2	1914	3
1892	3	1915	2
1893	4	1916	5
1894	3	1917	5
1895	3	1918	2
1896	4	1919	2
1897	6	1920	3
1898	3	1921	6
1899	5	1922	1
1900	4	1923	2
1901	3	1924	2
1902	6	1925	

We cannot do better in closing this review than to quote the summary given by Professor Olivier in his work, *Meteors*, elsewhere referred to:

1. There is no difference except mass and geocentric velocity between meteorites, fireballs, and meteors.

2. Representatives of all these three classes of bodies seem intimately connected with comets in our solar system. And possible connections between small asteroids, satellites, and comets' nuclei are appearing, in view of recent observations.

3. Large numbers of meteorites, fireballs, and meteors also come to us from outer space. This infers conditions in numerous stellar systems enough similar to our own to generate similar bodies.

The problem of source will probably only be solved through the accumulation of evidence bearing upon the apparent orbits. This, owing to the very brief period of observation and the unexpectedness of the phenomena and hence unpreparedness on the part of the competent observer, must be a matter of extreme slowness. We must be prepared to wait.

Dr. E. A. Wülfing, of Heidelberg, has issued for the guidance of observers a series of twenty questions concerning which information is desired, of which the following is a condensed translation:

A. Appearance of the meteor in the heavens.

1. At what time (day, hour, and minute) did the meteor appear?
2. How brilliant and how large was its appearance in comparison with celestial bodies or objects, whether like a star of the 5th, 4th, 3rd, 2nd, or 1st magnitude, or compared with Jupiter, Venus, or the moon?
3. What was the form, appearance, nature (shape) of the flash in various parts of the meteor's course—scintillating, flashing, diffused, explosive? (Sketch.)
4. What was its color?
5. How long did the light last in its entirety and in single portions of the course? Could variations in speed of the meteor be noted? Did it travel first rapidly, then move slowly, and finally come to a stop?

6. Did the meteor show a trail and leave a glowing train or smoke cloud?
7. How long did this remain visible?
8. What form did the smoke cloud assume with lapse of time?
9. What color did it have?
10. What position did the course of the meteor take in space, with reference to other celestial or terrestrial bodies?

B. Sound phenomena.

11. How much time elapsed after the first flash of the meteor before any sound was heard?
12. How long did the various noises last, and what were their characteristics?
13. Did many sounds, as crackling and hissing come very soon, *i.e.*, within a second after the flash, to the ear of the observer?

C. Observations on the fallen meteorite.

14. How much time elapsed after the fall before the meteorite was touched, or taken up?
15. Note the position of the observer and the distribution, according to size and weight, of the individual meteorites comprised in a single fall?
16. What was the nature of the soil? Were trees, shrubbery, or buildings affected?
17. How deeply did the meteorite, or any pieces of the same bury themselves in the ground? Did any lie on the immediate surface, or bound up from the ground?
18. What was the form and depth of the depression made by the meteorite, and was the earth compacted beneath it?
19. Was the meteorite hot or cold? Did the compressed material show signs of heat? Did the meteorite smoke, or give off any odor?
20. Did the meteorite strike the ground before or after the various sound phenomena?

It is of course not expected that any one individual will be able to answer all of the above. Fragmentary evidence is, however, of value if carefully recorded and placed in proper hands, such as any astronomical observatory or scientific institution where meteorites are being studied.

CHAPTER VIII

EARLY USES OF METEORIC IRON

It would seem but natural that a material like an iron meteorite, consisting largely of metal, should early have been put to some industrial use, and particularly before the discovery of processes for smelting metals from their ores. There is, however, in the whole course of history nothing, with a few quite unimportant exceptions, to show that meteorites were regarded as other than objects of veneration or curiosity. This, in some instances, as that of Canyon Diablo, seems really extraordinary, since this iron occurs locally in small, often sharply edged flakes scattered over a nearly verdureless plain where are today abundant signs of Indian occupancy. Yet there has to be recorded a single instance indicative that it was made use of or otherwise noticed by them.

One of the earliest authentic accounts bearing upon the subject which I find, is from the English *Philosophical Magazine* for 1803, and refers to a meteoric iron which fell in the pargana of Jalindher, Lahore, India, in 1620. Omitting sundry seemingly improbable details relative to the fall, the writer says:

> I committed it [the meteoric iron] to a skilful artisan with orders to make of it a sabre, a knife, and a dagger. The workman [soon] reported that the substance was not malleable, *but shivered into pieces under the hammer.*
>
> Upon this I ordered it to be mixed with other iron. Conformably to my orders three parts of the iron of lightning were mixed with one part of common iron; and from the mixture were made two sabres, one knife, and one dagger.
>
> By the addition of the common iron, the [new] substance acquired a fine temper; the blade proving as elastic as the most genuine blade

of Ulmanny and of the south, and bending like them without leaving any mark of the bend. I had them tried in my presence, and found them cut excellently; as well [indeed] as the best genuine sabres. One of these sabres I named *katai*, or the *cutter;* and the other, *burk-serisht*, or the *lightning-natured*.

In 1805, Mr. James Sowerby received from South Africa a piece of meteoric iron from which was forged a sword, which he presented to the Emperor of Russia with the following letter:[1]

May it please your Majesty:

The meteoric iron of which this blade has been hammered, was found about 200 miles within the Cape of Good Hope by Captain Barrow. It has been examined by my countryman Smithson Tennant, Esq., who established its nature by discovering about 10 per cent of nickel in it. It is the only sword ever made of that rare and extraordinary metal. That your Majesty may be graciously pleased to honor an humble individual by receiving it, is the ambitious hope of

Your Majesty's most obedient
and ever grateful servant,
Jas. Sowerby.

July 3, 1814.

The blade of this sword, we are informed, was hammered out at a red heat, but of a single piece without admixture of foreign material.

Its spring was given it by hammering when cold. The haft was lengthened by welding on a small piece of steel, it was found to work very pleasantly, the whole operation taking about 10 hours. The mounting and engraving occupied the two following days. Thus no sword was ever completed from the crude metal in so short a space of time. . . . The length of the sword is two feet; it is slightly curved, pointed and sharpened at both edges to eight inches from the point; its width is 1 inch and 3/8th. The surface is not quite free from blemish, in consequence of the spreading of some minute flaws in the material. . . . It possesses an excellent spring, much hardness, considering it is not steel, etc.

Fletcher, in his description of the Nejed, Arabia, meteorite,[2] mentions the sending of one of these irons by

[1] *Tilloch's Magazine*, Vol. 55, 1820, pp. 49–52.

[2] *Min. Mag.*, Vol. 7, 1886–87, p. 180.

the Hajee Ahmed Khane Sarteep, of Persia, to London to be made into weapons. With what success it is not definitely known, but H. A. Ward, the veteran collector, claims[3] to have purchased from Gregory of London the identical meteorite intact, leaving the natural and indeed only inference that the weapons returned to the Hajee were of artificial metal. Be this as it may, the date (1863) is too recent to make the matter of interest from the present standpoint.

F. Berwerth, writing in Tschermak's *Mittheilungen*,[4] states that five knives, or *krises* were made for the Austrian emperor from metal cut from the iron found in 1707 at Prambanan, Java, four months being devoted to the task. The amount of material necessary for the work was obtained by heating the large mass in a forge until it was sufficiently soft to be cut with hammer and chisel. He also states that knives of meteoric iron which render their wearers invulnerable are known in Arabia.

Dr. J. Gröneman states[5] that the Javanese krises are sometimes interwelded with meteoric iron, but he adds "Unser Empu (smiths) verwendet jetzt kein meteoreisen mehr" the nickel in the modern krises being imported from Germany.

The late Admiral Peary states in his book *Northward over the Great Ice*, that the mass of meteoric iron known as "The Woman" brought by him from Greenland has been reduced by successive chipping throughout many years fully one-half or one-third its bulk, the chips so obtained being used in making arrowheads, knives, and other rough cutting tools. It seems most probable that the implements with cutting edge made from meteoric irons found by the Danish Explorer Steenstrup in the Eskimo kitchen middens were from these same sources. The celebrated Tucson, or Ring meteorite was, when

[3] *Science*, Vol. 15, 1902, p. 150.

[4] Vol. 26, 1907, p. 506.

[5] *Internat. Arch. fur Ethnographie*, Vol. 19, 1909.

found, "set up on end and used as a kind of public anvil" by the natives, a practice not uncommon with other Mexican irons. The Chattooga, Georgia, Guilford, North Carolina, and Hollands Store irons were in part worked up by a local blacksmith into nails and horseshoes. Attempts at working the well-known Bitburg, Prussia, iron, on the other hand, resulted in failure.

At the sixth annual meeting of the Association of American Geologists, in 1845, Prof. C. U. Shepard described some metal-pointed spears, examples of which had been sent him, together with information relating thereto, by Lieut. H. C. Flagg, who had obtained them from natives of St. Augustine's Bay on the southwest coast of Madagascar. The metal had a specific gravity of 7.81 and contained iron, 96.66 per cent, and nickel, with traces of cobalt, 3.34 per cent. Shepard was, therefore, inclined to believe the material meteoric. So far as could be learned, it occurred in a native state in large masses but in a region which was at that time inaccessible to the party under Lieutenant Flagg's command. There are apparently two elements of doubt as to the meteoric nature of the material, however; first, its low per cent of nickel, and second, the number and large size of the masses described by the natives, some of them being stated to be sixteen feet in diameter. If meteoric, the locality would evidently outrival that of Canyon Diablo, and in sizes, those of both Greenland and Bacubirito.[6]

There are in the National Museum collection two fine blades, one fourteen inches in length from the Nejed iron, and one seven inches in length from the Coahuila iron, forged under the direction of the present writer by the local blacksmith. Both irons worked fairly well under the hammer, but neither could be tempered to a degree to give them more than very ordinary cutting power and little elasticity. Further tests showed that the Canyon

[6] Cohen examined a fragment of this iron in the Vienna Museum and pronounced it artificial. *Ann. k.k. Nat. Hof-museum*, Bd. 13, Heft 1, 1898, p. 57.

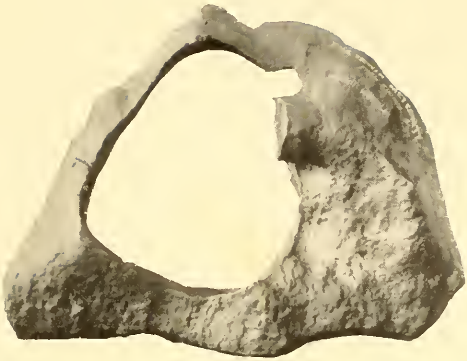
Diablo, Casas Grandes, Mt. Joy, New Baltimore, and other irons were all malleable even when cold, and when heated to redness could be beaten down to a knife-edge without cracking. The Toluca and Williamstown irons proved more refractory. It should be noted that, for these tests, clear, homogeneous portions were taken, free as possible from all evident enclosures of schreibersite or other minerals. None of the samples tested acquired any appreciable increase in hardness when subjected to the ordinary process of tempering steel. This fact militates strongly against the reported use in the manufacture of Damascan blades. There would appear no reason, however, for the malleable irons not having been utilized, so far as quality of material is concerned, though the ordinary shape of a meteoric mass is not such as to tempt one working only with implements of stone. But, as is elsewhere noted, that they were thus utilized is by no means proven, and seems quite unlikely. All assertions favorable to the idea, when critically examined, will be found based upon assumptions and "probabilities" that are not borne out by fact. They are but manifestations on the part of certain writers to make an actuality of a preconceived possibility.

The views here expressed accord with those of W. Gowland in his lectures on *The Metals of Antiquity* (1912); St. John and Day in *Prehistoric Use of Iron and Steel;* and Dr. L. Beck in *Geseicht der Eisen.*

It may be added that artificial iron was produced by the Hittites, according to Brested,[7] as early as the thirteenth century B.C., and was in common use among the Greeks as early as 1000 B.C.

In the prehistoric earthworks forming the Turner Group of Hamilton County, Ohio, there were found a few artifacts of meteoric iron. These included hollow beads and fragments of what may have been head plates, together with several small nuggets of unworked or but

[7] Ancient Science, a History of the Early World.



The celebrated Tucson, Arizona, meteoric iron. Height 97 centimeters, width 124 centimeters; weight 621,531 grams or about 1370 lbs.

This iron, otherwise known as the Signet, or Irwin-Ainsa meteorite was brought to the Smithsonian Institution in 1863 through the influence of Dr. B. J. D. Irwin, U. S. A. The original source of the iron is believed to have been the pass of Muchachos, in the Sierra de la Madera, whence it was brought by Spanish soldiers to the old Presidio where it remained until the withdrawal of the Spanish garrison. It was then taken to Tucson and set up as a "kind of public anvil for the use of the inhabitants." The mass was sent in 1860, from Tucson to Hermosillo, and later to Guaymas by the agency of Mr. Augustin Ainsa; in 1863 it was taken to San Francisco by J. M. Ainsa, and thence by Santiago Ainsa to Washington by way of the Isthmus of Panama. The iron as a whole consists of some 93.81 per cent nickeliferous iron, 5.06 per cent of olivine, and 1.25 per cent of chromic iron and schreibersite

slightly hammered metal.[8] A mass of meteoric material weighing 767.5 grams, taken from another of the mounds, contained included olivines, suggesting its probable identity with the pallasite of Kiowa County, Kansas. From the mounds of the Hopewell Group were found small cutting implements of iron made in the form of beaver teeth. Several ear ornaments and an adz blade of the same material were found in the mounds of the Liberty Group.

In the literature are to be found numerous citations bearing upon the early use of meteoric iron, but when traced back to their original sources, these are found to be based on mere assumption or on the few cases above referred to. There is, however, no question, but that the material from several American irons was worked into horseshoe nails to an inconsequential extent by country blacksmiths. This seems to have been done more out of curiosity than through actual need of material. A recent writer,[9] it is true, would extend the record to prehistoric times, but a careful reading of his paper shows that many of his citations are mere "probabilities" and have no basis of fact, though Rickard[10] seems to have accepted them without verification. The reference by the first-mentioned to the philosopher Averroës and the meteorite of Cordova is scarcely a happy one since the meteorite is referred to as a stone and, according to the reference in the *Annalen*,[11] Averroës was mistaken as to locality.

Neumayer, in his *Erdegeschichte* also mentions the early use of meteoric iron but gives no references, and the impression is gained that he is simply repeating unverified statements from other sources, an example followed by Miller.[12]

[8] The Turner Group of Earthworks, etc., *Papers Peabody Mus. Amer. Arch. and Eth., Harvard Uni.*, Vol. 8, No. 3, 1922.

[9] Zimmer. Use of iron by primitive man. *Journ. Iron & Steel Inst.*, 1916.

[10] *Eng. & Min. Journal-Press*, May 10, 1924, p. 700.

[11] Gilbert's *Annalen*, Vol. 18, 1804, p. 305.

[12] *Sci. Monthly*, Nov. 1923, p. 438.

FINALE

So ends the story. If to the reader the conclusions drawn or the information given seem disappointingly inconclusive let him turn back for but a moment to a consideration of the facts as they first presented themselves and upon which such conclusions are based.

In the early dusk of a winter's eve some years ago the writer was walking up the gentle incline of a New England city street, walled in on either hand by houses and a few trees. Suddenly, far up toward the end of the street, but low down in the horizon there appeared, seemingly from immediately behind one of the houses, a glaring ball of light which like an immense rocket (see frontispiece) passed across his field of vision and silently disappeared. It came and went in time scarce recorded by the ticking of a watch and left but a glow on the clouds and the wavy band of the phosphorized nitrogen such as is figured on page 32. There was no explosion, no falling to the earth of solid matter as described in many similar instances. Now will the reader tell me what there was in this momentary phenomenon on which to base conclusions as to what it was, its source, or significance as a natural occurrence? He will promptly answer, "Nothing." Yet it is upon the careful recording of all such phenomena—neglecting not the slightest detail of direction, speed, light, or character of the fallen body, if such there should be, that is based all that has been given in the previous pages. The summation is for today; tomorrow we may know more.

There is occasions and causes why and wherefore in all things. —*King Henry V*, Act 5.

It remains for us to find them.

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APPENDIX I

Classification of Meteorites

I. METEORIC STONES: AEROLITES

A. Meteorites rich in calcium- and aluminum-bearing minerals, poor in nickel-iron, and without chondrules.

Andrite. Consisting essentially of a calcium-rich augite with a little olivine and iron sulphide; structure crystalline granular.

Eukrite. Consisting essentially of augite and anorthite with a little sulphide of iron; structure basaltic.

Shergottite. Consisting essentially of augite and maskelynite with a little magnesia; structure crystalline granular.

Howardite. Consisting essentially of augite, anorthite, bronzite, and olivine; structure in part tuff-like and in part crystalline.

B. Meteorites rich in magnesian minerals, poor in nickel-iron, and for the most part without chondrules.

Bustite. Consisting essentially of diopside and bronzite with some plagioclase, nickel-iron, osbornite, and oldhamite; structure crystalline.

Chassignite. Consisting essentially of olivine and a little chromite; structure crystalline granular.

Chladnite. Consisting essentially of a rhombic pyroxene; structure crystalline granular.

Amphoterite. Consisting essentially of olivine and bronzite with a little iron sulphide and nickel-iron; structure sometimes granular, sometimes chondritic.

C. Meteorites rich in magnesian minerals and consisting essentially of olivine, bronzite, nickel-iron, and iron sulphide, with a fragmental or tufflike base and chondritic structure.

Howarditic Chondrites. A group intermediate between the chondrites and achondrites.

White Chondrites. Consisting of a yellowish white tufaceous base with chondrules mostly of the same color. This group is divided into three subgroups: (a) White chondrites (Cw); (b) veined white chondrites (Cwa); and (c) breccia-like white chondrites (Cwb).

Intermediate Chondrites. A group including forms intermediate between the white and the gray chondrites. This group is divided also into three subgroups: (a) Intermediate chondrites (Ci); (b) veined intermediate chondrites (Cia); and (c) breccia-like intermediate chondrites (Cib).

Gray Chondrites. Consisting of a yellowish to bluish gray tufflike base, with variously colored chondrules which are firmly imbedded in the groundmass. The group is divided into: (a) Gray chondrites (Cg); (b) veined gray chondrites (Cga); and (c) breccia-like gray chondrites (Cgb).

Black Chondrites. Consisting of a dark-gray to black firm chondritic mass, the color of which is due in part to carbon and in part to iron sulphide; chondrules mostly of a light color.

Spherulitic (Kugelchen) Chondrites. Consisting of numerous hard and well-formed chondrules in every varying proportion, in a tufflike or crystalline ground, sometimes so loosely imbedded as to break away from the ground and sometimes breaking with it. This group is divided into five subgroups as follows: (a) Ornansite and ngawite (Cco and Ccu); (b) spherical or Kugelchen chondrites (Cc); (c) veined Kugelchen chondrites (Cca); (d) breccia-like Kugelchen chondrites (Ccb); (e) crystalline Kugelchen chondrites (Cck).

Crsytalline Chondrites. Consisting of a crystalline groundmass with firmly imbedded chondrules. The group is divided into three subgroups: (a) Crystalline chondrites (Ck); (b) veined crystalline chondrites (Cka); (c) breccia-like crystalline chondrites (Ckb).

Carbonaceous Chondrites (K and Kc). This includes a group of chondritic stones impregnated with carbon and containing little or no iron.

Orvinite. A small group consisting of chondrules in a blackish ground, showing a fluidal structure. It has at present but one representative.

Tadjerite. Consisting of a dark, for the most part half glassy ground containing chondrules; without recognizable crust.

Urelite. Consisting essentially of olivine, sometimes chondritic and sometimes granular structure, of a dark, nearly black color, and often showing transition stages into the next class.

II. STONY IRON METEORITES: SIDEROLITES

Meteorites consisting of silicate minerals in a more or less disconnected mesh or sponge of nickel-iron.

Lodranite. Consisting of a crystalline granular mixture of olivine and bronzite in a fine, more or less disconnected network or sponge of metal.

Mesosiderite (Grahamite). Consisting essentially of olivine, bronzite, plagioclase, and augite, sometimes chondritic, sometimes crystalline granular, in a more or less interrupted network or sponge of metal.

Siderophyr. Consisting essentially of bronzite and nickel-iron with accessory asmanite in a network of nickel-iron of octahedral crystallization and showing Widmanstätten figures.

Pallasite. Consisting of olivine in a continuous network or sponge of metal.

Meteoric-Iron Breccia. Meteorites consisting of crystalline chondrules in a breccia-like mass of octahedral iron.

Meteoric Iron of Netschaëvo. Meteorites consisting of crystalline chondrules in a mass of octahedral nickel-iron.

III. NICKEL-IRON METEORITES: SIDERITES

Meteorites consisting essentially of nickel-iron with iron sulphide and phosphide, and usually graphite or other form of carbon.

Octahedral Irons. Consisting essentially of nickel-iron alloys arranged in the form of plates parallel to the faces of an octahedron, and often interlaminated with thin plates of schreibersite. On etching with acid they show Widmanstätten figures. According to the thickness of the plates they are divided as follows: (a) Octahedral irons with lamellae some 0.1 mm. in thickness (Off); (b) octahedral irons with lamellae 0.15 to 0.4 mm. in thickness (Of); (c) octahedral irons with lamellae 0.5 to 1.0 mm. in thickness (Om); (d) octahedral irons with lamellae 1.5 to 2.0 mm. in thickness (Og); (e) octahedral irons with lamellae over 2.5 mm. in thickness (Ogg); (f) breccialike octahedral irons (Obz).

Hexahedral Irons. Homogeneous masses of nickel-iron with evident cleavage parallel to the faces of a hexahedron and showing lamellae due to the twinning of a cube on an octahedral face. On etching they show Neumann lines. These are divided into: (a) Hexahedral irons (H); (b) brecciated hexahedral irons (Hb); (c) the Cape Iron group (Hca); (d) the Chesterville group (Hch).

MASSIVE IRONS. Amorphous irons showing neither Neumann nor Widmanstätten lines, nor other structural features such as permit satisfactory classification. Doctor Brezina has divided them into five groups: (a) The Babb's Mill group (Db); (b) the Nedagolla group (Dn); (c) the Primitiva group (Dp); (d) the Senegal group (Ds); (e) the Tucson group (Dt).

This classification, so far as it relates to the stony meteorites, has been modified by Prior[1] as follows:

I. Chondrites which, according to increasing percentages of nickel in the nickeliferous iron and corresponding increase of ferrous oxide in the magnesian silicates, are divided into:

(a) Enstatite-chondrites.
(b) Bronzite-chondrites.
(c) Hypersthene-chondrites.

To the members of each of these groups are applied the qualifications according to color (white, intermediate, gray, black); structure (crystalline, spherical, brecciated, veined); and composition (carbonaceous, etc.), used in the Tschermak-Brezina classification.

II. Achondrites. Divided, according to the content of lime, into:

(a) Calcium-poor achondrites which are subdivided into:

1. Enstatite-achondrites, or *Aubrites*, corresponding to the enstatite-chondrites.

[1] *Min. Mag.*, Vol. 19, 1920, pp. 51-63.

2. Clinobronzite-olivine-achondrites, or *Ureilites*, corresponding to bronzite-chondrites.

3. Hypersthene - olivine achondrites, or *Amphoterites* (and *Rodites*).
4. Hypersthene-achondrites, or *Diogenites*.
5. Olivine-achondrites, or *Chassignites*.

} corresponding to hypersthene chondrites.

(b) Calcium-rich achondrites, which are subdivided into:

1. Augite-achondrites, or *Angrites*.
2. Diopside-olivine-achondrites, or *Nakhlites*.
3. Clinohypersthene - anorthite - achondrites, or *Eukrites*; including *Shergottites* in which anorthite is replaced by maskelynite.
4. Hypersthene - clinohypersthene - anorthite - achondrites, or *Howardites*.

APPENDIX II

List of All Known Meteorites Seen to Fall, Portions of Which Have Been Preserved

I. STONES

Adhi Kot, Nurpur, Shahpur dist., Punjab, India.
Fell at noon on May 1, 1919.
A single stone of 4,239 grams weight.

Agen, Lot-et-Garonne, France.
Fell at noon, September 5, 1814.
A shower of stones the total weight of which was about 20 kilograms, the largest weighing about 9 kilograms.

Akbarpur, Saharanpur district, United Provinces, India.
Fell 8 a.m., April 8, 1838.
A single stone weighing about 4 pounds.

Alais, Gard, France.
Fell 5 p.m., March 15, 1806.
Two stones of about 4 and 2 kilograms weight respectively.

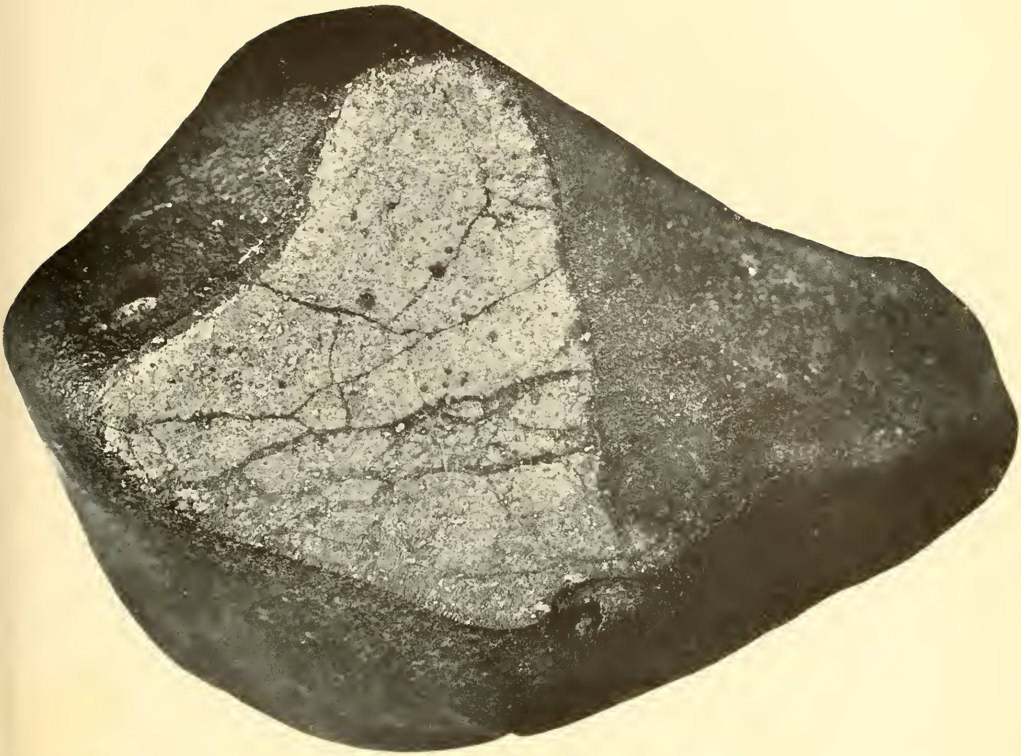
Albareto, Modena, Italy.
Fell 5 p.m., about the middle of July, 1766.
A single large stone weighing about 12 kilograms.

Aldsworth, Cirencester, Gloucestershire, England.
Fell 4:30 p.m., August 4, 1835.
A shower of small stones, the largest weighing about 1½ pounds.

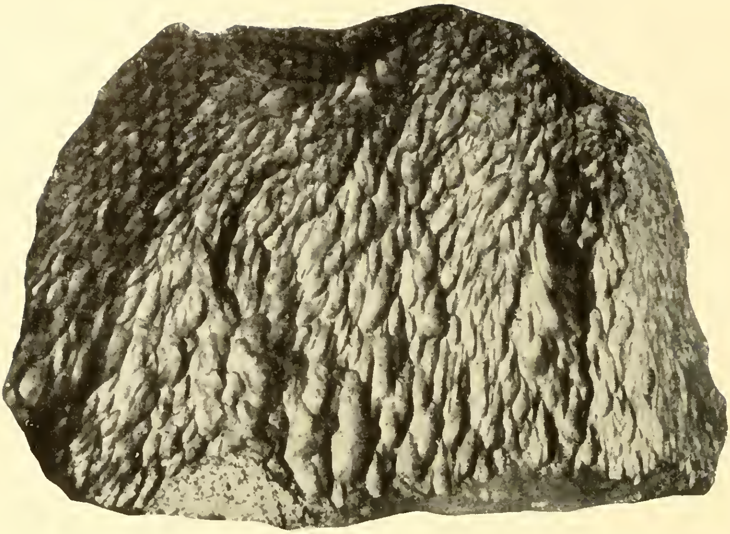
Alexandrovsky, Nyezhin dist., Chernigov govt., Ukraine.
Fell July 8, 1900.
One stone of 9.4 kilograms weight.

ALFIANELLO, Brescia, Italy.
Fell 3 p.m., February 16, 1883.
A single stone weighing about 228 kilograms.
ALLEGAN, Allegan County, Michigan.
Fell at 8 a.m., on July 10, 1899. (See Plate 5.)
A single stone weighing about 70 pounds broken in the fall.
ALLEPPO, Syria.
Thought to have fallen about 1873.
ALLESSANDRIA, Piedmont, Italy.
Fell 11:45 a.m., February 2, 1860.
Several stones from 300 grams to one kilogram each.
ALTAI, Tomsk, Siberia.
Fell at 11:30 p.m. on May 22, 1904.
A shower of small stones of which but six were preserved.
AMBAPUR NAGLA, Aligarh district, United Provinces, India.
Fell at 1 a.m. on May 27, 1895.
A single stone which broke in two pieces in falling.
ANDHARA, Muzzaffarpur district, Bengal, India.
Fell at 4 p.m. on Dec. 2, 1880.
A single stone weighing about 6 pounds (2,727 grams). This stone was made by the natives an object of adoration, and a temple built over it. (See page 38.)
ANDOVER, Oxford County, Maine.
Fell at 7:30 a.m. on Aug. 5, 1898.
A single stone weighing about 7 pounds (3,181 grams).
ANGERS, Maine-et-Loire, France.
Fell at 8:15 p.m. on June 3, 1822.
A single stone of about 1 kilogram weight.
ANGRA DOS REIS, Rio de Janeiro, Brazil.
Fell at 5 a.m. on Jan. 30, 1869.
A single stone weighing about 1,200 grams.
APPLEY BRIDGE, Lancashire, England.
Fell at 8:45 a.m. on Oct. 13, 1914.
A single stone weighing about 33 pounds (15 kilograms) found the day following the appearance of a luminous meteor.

PLATE 33



This meteoric stone, weighing 345 grams, fell Feb. 2, 1922, on the farm of Mr. Allen Cox about one and one-half miles west of Baldwyn, Mississippi. It was seen to fall by a negro tenant who was badly frightened and reported the occurrence to Mr. Cox who went with him and picked up the stone which had buried itself some three or four inches in soft clay. It was reported as still warm and giving off a smell very much like brimstone or flint when struck with a steel hammer. The attention of the colored man was first attracted by a humming noise which he mistook for an airplane. The noise increased for a moment when a rush of air was felt and the stone buried itself near his feet. He did not at any time see the stone until it hit the ground although the sound was first heard in a northwesterly direction



Meteoric Stone, Bath Furnace, Kentucky.

This beautiful stone, one of three constituting the entire fall, so far as known, fell early in the evening of Nov. 15, 1902, accompanied by a glaring light and heavy detonations. Two of the three pieces were recovered within a few hours; the third shown in the figure was not found until May of 1903. The stone, which is now in the Field Museum, of Chicago, weighs 177¼ pounds or 80 kilograms and is remarkable for the beauty and perfection of its flutings which radiate from the apex in all directions

APT, Vaucluse, France.
Fell at 10:30 a.m., Oct. 8, 1803.
A single stone weighing about 3,250 grams.
ASSISSI, Perugia, Italy.
Fell at 7 a.m. on May 24, 1886.
A single stone of about 2 kilograms weight.
ATARRA, Manikpur, Banda dist., United Provinces, India.
Fell at 5:35 p.m., Dec. 23, 1920.
Three stones of 1,280 grams weight.
ATEMAJAC, Sierra de Topalpo, Jalisco, Mexico.
Fell on Feb. 2, 1896.
A small stone of which little is yet known.
AUBRES, Nyons, Drôme, France.
Fell at 3 p.m. on Sept. 14, 1836.
A single stone of some 800 grams weight.
AUMALE, Alger, Algeria.
Fell between 11 and 12 a.m. on Aug. 25, 1865.
Two stones of about 25 kilograms each.
AUMIÈRES, Lozère, France.
Fell at 9 p.m. on June 3, 1842.
A single stone of about 2 kilograms weight.
AUSSUM, Haute Garonne, France.
Fell at 7:30 a.m. on Dec. 9, 1858.
Two stones of about 9 and 41 kilograms weight.
AVILEZ, Cuencamé, Durango, Mexico.
Fell in June, 1855.
A shower of "several" stones but only a few small pieces saved.
BACHMUT, Ekaterinoslav, Ukraine.
Fell at noon on Feb. 15, 1814.
A single stone of 18 kilograms weight.
BALDWYN, Lee County, Mississippi.
Fell in the daytime, Feb. 2, 1922.
One small stone of 345 grams weight. (See Plate 33.)
BALI mission station, Cameroon, West Africa.
Fell at 11 a.m., Nov. 22 or 23, 1907.
Fall noted, but no description.

Bandong, Java.
Fell at 1:30 p.m., Dec. 10, 1871.
Six stones fell, of a total weight of about 11,500 grams.

Banswal, Dehra Dun district, United Provinces, India.
Fell at 6 p.m. on Jan. 12, 1913.
A single stone fell of unknown weight, and of which but about 14 grams were saved.

Barbotan, Landes, France.
Fell at 9 p.m. on July 24, 1790.
A shower of stones, the largest weighing 9,000 grams.

Barntrup, Lippe, Germany.
Fell on May 28, 1886.
A small stone of but 17 grams.

Baroti, Bilaspur, Simla Hill States, Punjab, India.
Fell at 10 a.m. on Sept. 15, 1910.
But one stone, of about 4,041 grams weight.

Bath, Brown County, South Dakota.
Fell at 4 p.m. on Aug. 29, 1892.
One stone of about 21,250 grams.

Bath Furnace, Bath County, Kentucky.
Fell at 6:45 p.m. on Nov. 15, 1902.
Three stones fell, the largest, remarkable for the perfection of its flutings, weighing 80,455 grams. (See Plate 34.)

Beaver Creek, West Kootenay district, British Columbia.
Fell at 3:30 p.m., May 26, 1893.
A single stone weighing 14,909 grams.

Benares, United Provinces, India.
Fell at 8 p.m., Dec. 19, 1798.
A shower of stones, one of about 2 pounds weight passing through the roof of a hut.

Bereba, Haute Volta, French West Africa.
Fell at 3:30 p.m., June 27, 1924.
One stone of about 18 kilograms belonging to the rare group of eukrites.

BERLANGUILLAS, Burgos, Spain.
Fell at 8 p.m. on July 8, 1811.
Three stones known to have fallen, the largest weighing about 2,500 grams.

BETHLEHEM, Albany County, New York.
Fell at 7:30 a.m., Aug. 11, 1859.
A single small stone the size of a pigeon's egg.

BEUSTE, Pau, Basse-Pyrénées, France.
Fell on an afternoon in May, 1859.
Two fragments known weighing respectively 1,500 and 500 grams.

BHERAI, Junagarh, Kathiawar, Bombay, India.
Fell at 8 a.m. on April 28, 1893.
A small stone of less than one fourth of a gram.

BHOLGHATI, Deoli pargana, Maurbhanj, Orissa, India.
Fell at 8:30 a.m. on Oct. 29, 1905.
Two stones of about 909 and 1,591 grams.

BIALYSTOK, Grono, Poland.
Fell at 9:30 a.m., Oct. 5, 1827.
A shower of stones, of which but 4 weighing all told 4,000 grams were found.

BIELOKRYNITSCHIE, Zaslavl, Volhynia, Ukraine.
Fell at 6 p.m. on Jan. 1, 1887.
A shower of which eight were found the largest weighing 2 kilograms.

BISHOPVILLE, Sumter County, South Carolina.
Fell Mar. 25, 1843.
A single stone of about 13 pounds (5,909 grams) belonging to the rare group of aubrites of which but three representatives are known.

BISHUNPUR, Mirzapur district, United Provinces, India.
Fell at 3 p.m. on April 26, 1895.
Four stones reported to have fallen, but only two small ones weighing 97 and 942 grams preserved.

BJELAJA ZERKOV, Kiev, Ukraine.
Fell on Jan. 15, 1796.
One individual weighing 1,400 grams.

Bjurböle, Borga, Nyland, Finland.
Fell at 10:30 p.m. on Mar. 12, 1899.
Several stones of which the largest weighed 80 kilograms; the total weight of all being 330 kilograms.
Blanket, Brown County, Texas.
Fell at 10:30 p.m. on May 30, 1909.
Two stones weighing respectively 1,500 and 1,600 grams.
Blansko, Brno, Moravia, Czechoslovakia.
Fell at 6:30 p.m., Nov. 25, 1833.
A shower of stones eight of which, weighing altogether but 350 grams, were found.
Bocas, San Luis Potosi, Mexico.
Fell Nov. 24, 1804.
But small fragments and little information regarding this fall known.
Borgo San Donnino, Parma, Italy.
Fell at noon on April 19, 1808.
Several stones fell, the largest weighing about 1 kilogram.
Bori, Betul district, Central Provinces, India.
Fell at 4 p.m. on May 9, 1894.
A single stone of about 8,636 grams.
Borkut, Marmoros, Ruthenia, Czechoslovakia.
Fell at 3 p.m. on Oct. 13, 1852.
A single stone weighing about 7 kilograms.
Borodino, Moscow, Russia.
Fell at 1 a.m. on Sept. 5, 1812.
A single stone weighing about 500 grams.
Botschetschki, Kursk, Russia.
A stone of 614 grams weight said to have fallen at the end of 1823.
Bremervörde, Hanover, Germany.
Fell at 5 p.m. on May 13, 1855.
Five stones known of this fall, weighing altogether 7,250 grams, the largest 2,750 grams.
Bur-Gheluai, Bur-Hagaba district, Italian Somaliland.
Fell at 8 a.m. on Oct. 16, 1919.

A shower of over 100 stones of a total weight of about 120,000 grams, the largest 15,400 grams.

Buschhof, Zemgale, Latvia.
Fell at 7:30 a.m. on June 2, 1863.
A single stone of about 5,000 grams.

Bustee, bet. Gorakhpur and Fyzabad, Basti district, United Provinces, India.
Fell at 10 a.m., Dec. 2, 1852.
A type of exceedingly rare meteorite weighing about 1,600 grams and containing a nodular mass from which were first described the minerals osbornite and oldhamite.

Butsura, Champaran district, Bihar, India.
Fell about noon on May 12, 1861.
There were five stones in this fall and although scattered at intervals of 2-3 miles apart, all could be fitted together showing that they were once portions of the same mass.

Cabeza de Mayo, Murcia, Spain.
Fell at 6:15 a.m. on Aug. 18, 1870.
A single stone weighing some 25 kilograms.

Canellas, Barcelona, Spain.
Fell at 1:30 p.m. on May 14, 1861.
Several stones which were mostly lost or broken into small fragments.

Cangas de Onis, Asturias, Spain.
Fell at 11 a.m. on Dec. 6, 1866.
A shower of stones of which the largest weighed about 11,000 grams.

Cape Girardeau, Cape Girardeau County, Missouri.
Fell at 3 p.m. on Aug. 14, 1846.
One stone of about 5 pounds (2,272 grams) weight.

Caratash, Smyrna, Asia Minor.
Fell at 8 p.m., Aug. 22, 1902.
One stone as "big as a melon."

Castalia, Nash County, North Carolina.
Fell at 2:30 p.m., May 14, 1874.

A dozen or more stones fell over an area 3 × 10 miles, but only 3 of 800 grams, 1,000 grams and 5,500 grams preserved.

Castine, Hancock County, Maine.
Fell at 4 a.m., May 20, 1848.
A single stone of but about 3 ounces weight.

Cereseto, Casale, Piedmont, Italy.
Fell at 7:30 a.m. on July 17, 1840.
One stone of about 5,000 grams weight.

Chail, Allahabad, United Provinces, India.
Fell at 4:30 p.m. on Nov. 5, 1814.
Nineteen stones, some of them up to 18,181 grams, said to have fallen.

Chainpur, Azamgarh district, United Provinces, India.
Fell at 1:30 p.m., May 9, 1907.
Several stones of varying weights up to 12 pounds (5,458 grams).

Chandakapur, Berar, Central Provinces, India.
Fell at noon of June 6, 1838.
Three stones weighing about 8,864 grams.

Chandpur, Mainpuri district, United Provinces, India.
Fell April 6, 1885.
A single stone of about 2½ pounds was heard to fall and was found next day.

Changanorein, Cochin State, India.
Fell at 12:45 p.m., July 3, 1918.
Seven small stones, the largest, a fragment, weighing 713 grams.

Chantonnay, Vendée, France.
Fell at 2 a.m., Aug. 5, 1812.
A stone of 31½ kilograms fell.

Charsonville, Meung, Loiret, France.
Fell at 1:30 p.m., Nov. 23, 1810.
Three stones of 9 to 18 kilograms.

Charwallas, Hissar district, Punjab, India.
Fell at 8 a.m. on June 12, 1834.

A single stone weighing 12,045 grams, which has now been almost completely lost.

Chassigny, Haute Marne, France.
Fell at 8 a.m. on Oct. 3, 1815.
Four kilograms of fragments.

Chateau Renard, Montargis, Loiret, France.
Fell at 1:30 p.m., June 12, 1841.
A single stone of some 30 pounds (1,364 grams) weight.

Chervettaz, Palézieux, Vaud, Switzerland.
Fell at 2 p.m. on Nov. 30, 1901.
One stone of about 750 grams weight.

Clohars, Fouesnant, Quimper, Finistère, France.
Fell on June 21, 1822.
But six grams of the material known.

Colby, Clark County, Wisconsin.
Fell at 6:20 p.m. on July 21, 1917.
Two stones weighing respectively 80 and 150 pounds fell and broke into pieces.

Cold Bokkeveld, Cape Province, South Africa.
Fell at 9 a.m. on Oct. 13, 1838.
Many stones fell, the largest of about 2 kilograms weight.

Collescipoli, Terni, Umbria, Italy.
Fell at 1:30 p.m., Feb. 3, 1890.
A single stone of about 5 kilograms.

Constantia, near Cape Town, South Africa.
Fell at 4:30 p.m., Nov. 4 (?) 1906.
A single stone of about 2 pounds weight fell through the roof of a house.

Cosina, Dolores Hidalgo, Guanajuato, Mexico.
Fell at 11 a.m. in Jan., 1844.
One stone of about 1,200 grams.

Cranganore, Cochin State, Madras, India.
Fell 12:45 p.m., July 3, 1917.
Six stones fell of weight upwards of 1,460 grams.

Cronstad, Orange Free State, South Africa.
Fell at 4 p.m. on Nov. 19, 1877.

A shower of stones, the largest of which weighed about 2,727 grams.

CROSS ROADS, Boyett, Wilson County, North Carolina.
Fell at 5 a.m. on May 24, 1892.
One stone of but 167 grams weight.

CRUMLIN, County Antrim, Ireland.
Fell at 10:30 a.m. on Sept. 13, 1902.
One stone of about 9 pounds 5½ ounces.

CUMBERLAND FALLS, Whitley County, Kentucky.
Fell at noon on April 9, 1919.
Several stones, the largest estimated to have weighed some 30 pounds though it smashed in falling. A coarse brecciated stone of exceptional interest.

CYNTHIANA, Harrison County, Kentucky.
Fell at 4 p.m. on Jan. 23, 1877.
One stone of about 6,000 grams.

DANDAPUR, Gorakhpur district, United Provinces, India.
Fell at 5 p.m., Sept. 5, 1878.
Two stones of about 6½ and 5½ pounds weight.

DANIELS KUIL, Griqualand West, South Africa.
Fell on March 20, 1868.
One stone of 2 pounds 5 ounces weight.

DANVILLE, Morgan County, Alabama.
Fell at 5 p.m., Nov. 27, 1868.
Several stones fell, but one preserved, weight 4½ pounds.

DEAL, Long Branch, Monmouth County, New Jersey.
Fell about 12:30 a.m., Aug. 15, 1829.
Several reported as fallen, but one small one preserved.

DE CEWSVILLE, Haldimand County, Ontario, Canada.
Fell at 2 p.m. on Jan. 21, 1887.
One stone only of 340 grams.

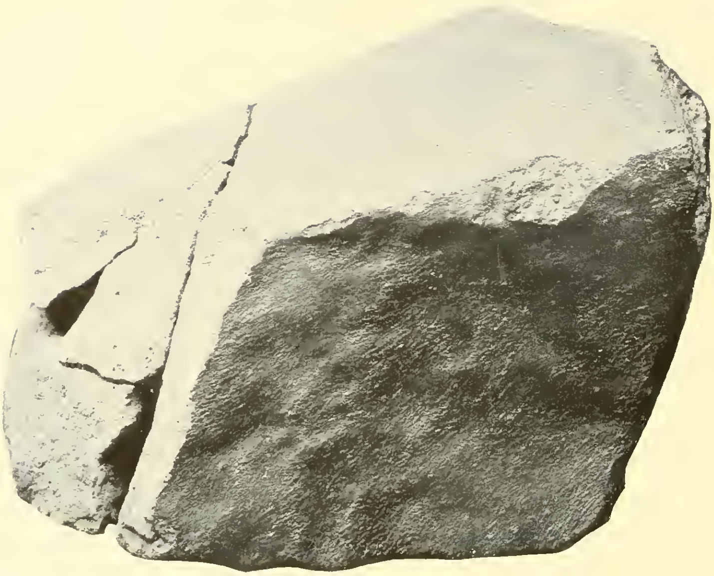
DELHI, Punjab, India.
Fell Oct. 18, 1897.
Two stones of 1 pound weight each.

DEMINA, Biysk dist., Altai govt., Siberia.
Fell Sept. 6, 3:30 p.m., 1911.
One or more stones of 16.4 kilograms weight.

PLATE 35

Fragment from the Ensisheim stone that fell Nov. 16, 1492. For description see p. 7

PLATE 36



The meteoric stone that fell at Felix, Alabama, on May 15, 1900. About natural size. Weight 2,049 grams. The fall was accompanied by one very loud report followed by two lesser ones, the appearance being compared to that of a big piece of red hot iron being struck with a hammer causing many sparks to fly in all directions. Two smaller pieces fell which have become lost

DHAWAR, Bombay, India.
Fell at 1 p.m., Feb. 15, 1848.
One stone of about 4 pounds weight.

DHURMSALA, Kangra district, Punjab, India.
Fell at 2:15 p.m. on July 14, 1860.
A fall of unusual interest. Several stones, of which the largest weighed 329 pounds.

DIEP RIVER, Cape Province, South Africa.
Fell 1906.
One stone, weight not given.

DJATI-PENGILON, Ngawi district, Java.
Fell at 4:30 p.m. on Mar. 19, 1884.
A single stone of about 166 kilograms (356 pounds).

DOKACHI, Dacca district, Bengal, India.
Fell at 7 p.m. on Oct. 22, 1903.
Over 100 stones fell, of which 24 were preserved.

DOLGOVOLI, Luck, Wolyn, Poland.
Fell at 7 a.m. on June 26, 1864.
A single stone of about 1.6 kilograms.

DOMANITCH, Carakewy, Brusa, Asia Minor.
Fell Feb. 1, 1907.
Two small stones, not described.

DONGA KOHROD, Bilaspur district, Central Provinces, India.
Fell at 3 p.m. on Sept. 23, 1899.
A single stone of about 1 kilogram.

DORONINSK, Irkutsk, Siberia.
Fell at 5 p.m. on Apr. 6, 1805.
Two stones of total weight of 4.25 kilograms.

DRAKE CREEK, Nashville, Sumner County, Tennessee.
Fell at 4 p.m., May 9, 1827.
Five stones, the largest of 11½ pounds, were seen to fall.

DUNDRUM, County Tipperary, Ireland.
Fell at 7 p.m., Aug. 12, 1865.
A single stone of 4 pounds 14½ ounces weight.

DURALA, N. W. of Karnal district, Punjab, India.
Fell at noon on Feb. 18, 1815.
A single stone of about 29 pounds weight.

Duruma, Mombasa, Wanikaland, East Africa.
Fell on Mar. 6, 1853.
A single stone of about 577 grams weight.

Dyalpur, Sultanpur district, United Provinces, India.
Fell on May 8, 1872.
A stone of but 10 ounces weight.

Eichstädt, Middle Franconia, Bavaria.
Fell at 12:15 p.m. on Feb. 19, 1785.
A stone of about 3 kilograms weight.

Ekh Khera, Bisauli tahsil, Budaun district, United Provinces, India.
Fell at 2:30 a.m., April 5, 1916.
A stone of about 840 grams weight.

Ellemeet, Isle of Schouwen, Zeeland, Holland.
Fell at 11:30 a.m., Aug. 28, 1925.
Two stones of 970 and 500 grams belonging to the rare group of rodites.

Ensisheim, Alsace, France.
Fell at 11:30 p.m. on Nov. 16, 1492.
A single stone of 127 kilograms weight, and of special interest for being the oldest known fall of which samples have been preserved. (See Plate 35.)

Épinal, Vosges, France.
Fell at 7 a.m. on Sept. 13, 1822.
A single stone of "about the size of a 6-pound cannon ball."

Ergheo, Brava, Italian Somaliland, E. Africa.
Fell in July, 1889.
A stone of about 20 kilograms weight.

Erxleben, Magdeburg, Prussia.
Fell at 4 p.m. on April 15, 1812.
A stone of about 2.25 kilograms weight.

Esnandes, Charente-Inférieure, France.
Fell in August, 1837.
One stone of about 1.5 kilograms weight.

Estherville, Emmet County, Iowa.
Fell at 5 p.m. on May 10, 1879.

A shower of several large and many smaller masses, having a total weight of over 700 pounds. These meteorites belong to the class of mesosiderites and are of unusual interest, being apparently a metamorphosed agglomerate.

FARMINGTON, Washington County, Kansas.
Fell at 1 p.m. on June 25, 1890.
Two stones seen to fall, one of 188 pounds and the second of 9 pounds.

FAVARS, Aveyron, France.
Fell at 6:45 a.m. on Oct. 21, 1844.
A single stone of 15 kilograms.

FEID CHAIR, La Calle, Constantine, Algeria.
Fell at midday, August 16, 1875.
A single stone of 380 grams weight.

FELIX, Perry County, Alabama.
Fell at 11:30 a.m., May 15, 1900.
Stone of about 2 kilograms weight. (See Plate 36.)

FENG-HSIEN, northern Kiangsu, China.
Fell at 6:22 p.m., Oct. 5, 1924.
Stones fell of which but 82 grams are noted.

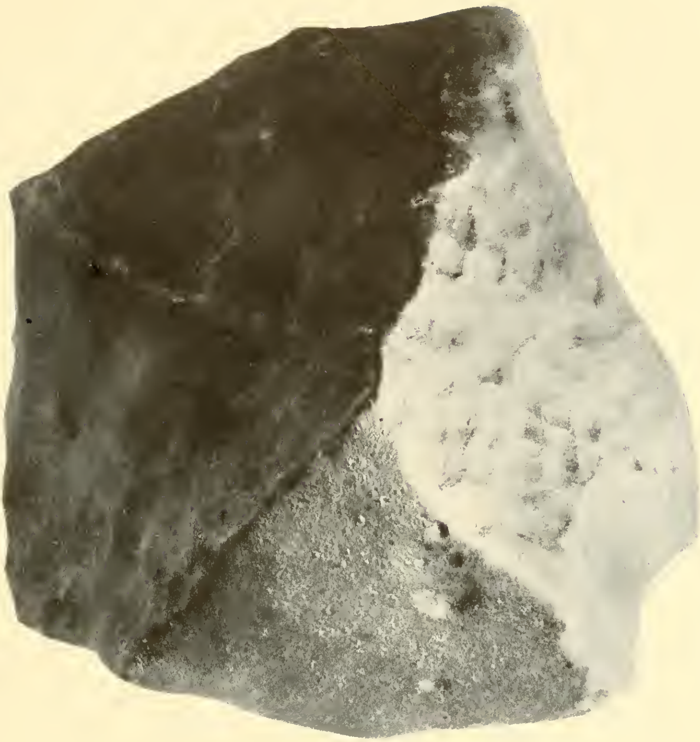
FERGUSON, Haywood County, North Carolina.
Fell July 18, 1889.
A single stone of about ½ pound weight.

FISHER, Polk County, Minnesota.
Fell at 4 p.m. on Apr. 9, 1894.
Several stones found, the largest of which was broken up and lost, the largest remaining of about 9¼ pounds weight. (See Plate 37.)

FOREST CITY, Winnebago County, Iowa.
Fell at 5:15 p.m. on May 2, 1890.
A shower of 5 large and over 500 smaller ones of a total weight of over 125 kilograms.

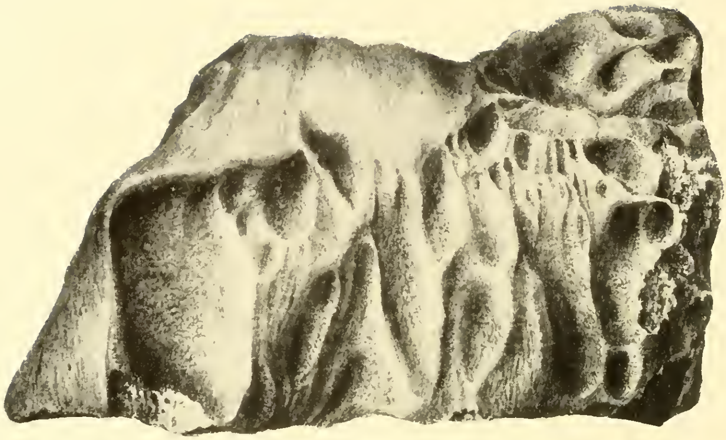
FORKSVILLE, Mecklenburg County, Virginia.
Fell about 5:45 p.m., July 16, 1924.
Four stones of 853, 1,114, 1,850 and 2,250 grams weight.

FORSBACH, Hoffnungsthal, Cologne, Rhenish Prussia.
Fell at 2 p.m. on June 12, 1900.
A single stone of but 240 grams weight.
FORSYTH, Monroe County, Georgia.
Fell at 3:30 p.m., May 8, 1829.
A single stone of 36 pounds weight.
FRANKFORT, Franklin County, Alabama.
Fell at 3 p.m., Dec. 5, 1868.
A stone of about 650 grams.
FUKUTOMI, Kijima, Hizen, Japan.
Fell at 1 p.m., March 19, 1882.
Two stones weighing about 9.75 kilograms.
FUTTEHPUR, Allahabad district, United Provinces, India.
Fell at 6 p.m. on Nov. 30, 1822.
Several stones weighing from 1 to 4 pounds each.
GALAPIAN, Agen, Lot et Garonne, France.
Fell in August (?) 1826.
One large stone said to have fallen as above.
GAMBAT, Khairpur State, Bombay, India.
Fell on Sept. 15, 1897.
One stone of about 14 pounds weight.
GIFU, Mino, Japan.
Fell at 5:44 a.m. on July 14, 1909.
A shower of over 100 pieces.
GIRGENTI, Sicily, Italy.
Fell at 1 p.m., Feb. 10, 1853.
Several stones, the largest of about 7 pounds weight.
GLASATOVO, Kashin, Tver govt., Russia.
Fell at 12:45 p.m., Feb. 27, 1918.
One stone of over 150 kilograms.
GNADENFREI, Silesia.
Fell at 4 p.m., on May 17, 1879.
Two stones of about 1,000 and 750 grams weight.
GOPALPUR, Jessore district, Bengal, India.
Fell at 6 p.m. on May 23, 1865.
One stone of about 1,600 grams. (See Plate 38.)



One of the fragments from the fall at Fisher, Polk County, Minnesota, April 9, 1894. Note the primary crust on the bottom and secondary on the right. Weight 4,340 grams

PLATE 38



Side view of the meteorite of Gopalpur, India, which fell on May 3, 1865. Weight 1.6 kilograms

GRAZAC, Tarn, France.
Fell at 4 a.m. on Aug. 10, 1885.
Shower of about 20 stones, the largest weighing about 600 grams.

GROSNAJA, Mekensk, Terek, Caucasus.
Fell at 7 p.m. on June 28, 1861.
A shower of which but about 3,500 grams were recovered, the rest having fallen in the River Terek.

GROSS-DIVINA, Sillein, Trencsen, Czechoslovakia.
Fell at 11:30 a.m. on July 14, 1837.
One stone of about 10½ kilograms.

GROSSLIEBENTHAL, Odessa, Ukraine.
Fell at 6:30 a.m. on Nov. 19, 1881.
One stone of about 8 kilograms weight.

GRÜNEBERG, Silesia.
Fell at 3:30 p.m. on March 22, 1841.
One stone of about 1 kilogram weight.

GUAREÑA, Badajos, Spain.
Fell at 10:30 a.m. on July 20, 1892.
Two stones weighing 25 and 7 kilograms.

GUĚA, Serbia.
Fell on Sept. 28, 1891.
A single stone of unknown weight of which a fragment weighing 1,915 grams is preserved.

GUMOSCHNIK, Trojan, Bulgaria.
Fell at 6:20 p.m. on Apr. 28, 1904.
Five or six stones aggregating 5.7 kilograms weight and the largest 3.8 kilograms.

GUTERSLOH, Westphalia, Germany.
Fell 8 p.m. on Apr. 17, 1851.
A single stone of 1 kilogram weight.

HARAIYA, Basti district, United Provinces, India.
Fell in August or September, 1878.
One stone of about 1 kilogram weight.

HARIPURA, Jaipur State, Rajputana, India.
Fell at 9 p.m., Jan. 17, 1921.
Stone, weight not given.

HARRISON COUNTY, Indiana.
Fell at 4 p.m. on March 28, 1859.
A shower of which but four of a total weight of about 750 grams were preserved.

HEDESKOGA, Ystad, Sweden.
Fell at 7:45 p.m., April 20, 1922.
One stone of 3.5 kilograms weight.

HEDJAZ, Arabia.
Fell in the night during the spring of 1910.
Four stones, the largest weighing 4 kilograms.

HEREDIA, San José, Costa Rica.
Fell in the night on Apr. 1, 1857.
A shower of which the largest weighed about 1 kilogram.

HESSLE, Upsala, Sweden.
Fell at 12:30 p.m. on Jan. 1, 1869.
A shower of stones which fell over an oval area 3×9 miles, the largest weighing about 1.8 kilograms. The shower was particularly remarkable for the powdery carbonaceous matter associated with it. (See Plate 39.)

HIGASHI-KOEN, Fukuoka, Chikuzen, Japan.
Fell on August 11, 1897.
One stone of 750 grams weight.

HIGH POSSIL, Glasgow, Lanarkshire, Scotland.
Fell on the morning of April 5, 1804.
One stone of about 4,545 grams weight.

HOLBROOK, Navajo County, Arizona.
Fell at 7:15 p.m. on July 19, 1912.
One of the most remarkable showers on record, numbering over 14,000 separate pieces weighing from the fraction of an ounce to 6,600 grams.

HOLETTA, Addis-Ababa, Abyssinia.
Fell at 11:25 a.m., April 14, 1923.
One stone of 1,415 grams.

HOMESTEAD, Iowa County, Iowa.
Fell at 10:15 p.m. on Feb. 12, 1875.
A shower of over 100 stones of an aggregate weight of

227,270 grams (500 pounds) the largest weighing 33,636 grams (74 pounds.)

HONOLULU, Oahu, Hawaiian Islands.
Fell at 10:30 a.m. on Sept. 27, 1825.
Several stones of a total weight unknown. The two largest preserved of about 1.5 kilograms weight.

HUNGEN, Hesse, Germany.
Fell at 7 a.m. on May 17, 1877.
But two stones found weighing 86 and 26 grams.

HVITTIS, Abo, Finland.
Fell at noon, Oct. 21, 1901.
One stone of 14 kilograms weight.

IBBENBUHREN, Westphalia, Germany.
Fell at 2 p.m. on June 17, 1870.
A stone belonging to the rare group of chladnites of which less than half a dozen are known. Total weight about 2 kilograms.

INDARCH, Shusha, Elisavetpol, Transcaucasia.
Fell at 8:10 p.m. on Apr. 17, 1891.
A stone of about 27 kilograms.

ITAPICURU-MIRIM, Maranhao, Brazil.
Fell in March, 1879.
One stone of about 2 kilograms weight.

JACKALSFONTEIN, Beaufort West, Cape Province, South Africa.
Fell at 11:30 a.m. on Apr. 22, 1903.
Two stones, weight not given.

JAJH DEH KOT LALU, Faizganj taluk, Khairpur State, Sind, India.
Fell between 5 and 6 p.m., May 2, 1926.
Two pieces recovered weighing 220 and 753 grams.

JAMKHEIR, Ahmadnagar district, Bombay, India.
Fell at noon on Oct. 5, 1866.
Two small stones, weight not given.

Jellica, Serbia.
Fell at 2:30 p.m. on Dec. 1, 1889.
A shower of stones belonging to the rare group of amphoterites. The individual stones weighed from a few grams to 8.5 kilograms.

Jhung, Punjab, India.
Fell at 3 p.m. in June, 1873.
Four stones weighing altogether some 13 pounds or 6 kilograms.

Jodzie, Panevezys, Kovno, Lithuania.
Fell at 4:30 a.m. on June, 1887.
A single stone of weight unknown; all but a few fragments being lost.

Johnstown, Weld County, Colorado.
Fell at 4:20 p.m., July 6, 1924.
Twenty-seven stones, of which about 40.5 kilograms were recovered, the largest weighing 23.5 kilograms. Belongs to the rare group of diogenites.

Jonzac, Charente Inférieure, France.
Fell at 6 a.m. on June 13, 1819.
A shower of stones belonging to the class of eukrites, of which but four representatives were then known. The two largest stones weighed but 2 and 3 kilograms.

Judesegeri, Tumkur district, Mysore, India.
Fell in the evening of Feb. 16, 1876.
A single stone of which but about 750 grams were preserved.

Juvinas, Libonnès, Antraigues, Ardèche, France.
Fell at 3 p.m. on June 15, 1821.
One stone of over 91 kilograms weight, belonging with that of Jonzac above to the class of eukrites.

Kaba, Debreezen, Hungary.
Fell at 10 p.m. on Apr. 15, 1875.
A single stone weighing about 3 kilograms.

Kadonah, Agra district, United Provinces, India.
Fell on the night of Aug. 7, 1822.
A large stone, but weight not recorded.

PLATE 39

A completely encrusted individual from the meteoric shower at Hessle, Sweden, Jan. 1, 1869. Weight 282 grams. A large number of stones fell which were distributed over an area of some 3 × 9 miles, some of them falling on thin ice without breaking it or being broken. In this respect the fall stands in marked contrast with that of Kilbourn.

(See p. 18)

Meteoric stone. Natural size. Fell at Kilbourn, Wisconsin, June 16, 1911, penetrating three thicknesses of shingles and two boards of the roof and floor of a barn. When first picked up, it is stated to have been too warm to hold comfortably. As the stone is small it would seem probable that it was travelling at a very high rate of speed and in a retrograde direction

KAGARLYK, Kiev dist., Kiev govt., Russia.
Fell at 7 a.m., June 30, 1908.
One stone of about 1.9 kilograms.

KAKANGARI, Tirupathurt taluk, Salem, Madras, India.
Fell at 8 a.m. on June 4, 1890.
Two small stones, total weight unknown; about 340 grams saved.

KAKOWA, Oravicza, Krassó-Szörény, Rumania.
Fell at 8 a.m. on May 19, 1858.
A single fragment of 577 grams only.

KALUMBI, Satara district, Bombay, India.
Fell on Nov. 4, 1879.
One stone of about 4½ kilograms weight.

KAMSAGAR, Shimoga district, Mysore, India.
Fell at 1 p.m. on Nov. 12, 1902.
One stone of 1,293 grams weight.

KARAKOL, Ayagus, Semipalatinsk, Siberia.
Fell at noon on May 9, 1840.
A single stone of about 3 kilograms weight.

KARKH, Jhalawan, Baluchistan, India.
Fell at 1 p.m. on Apr. 27, 1905.
Six pieces found, weighing 22 kilograms.

KERILIS, Maël Pestivien, Callac, Côtes-du-Nord, France.
Fell at 10:30 a.m. on Nov. 26, 1874.
One stone of about 5 kilograms weight.

KERNOUVE, Morbihan, France.
Fell at 10 p.m. on May 22, 1869.
A single stone of about 80 kilograms weight.

KESEN, Rikuzen, Japan.
Fell at 5 a.m. on June 12, 1850.
A single stone of about 135 kilograms weight.

KHAIRPUR, Bahawalpur State, Punjab, India.
Fell at 5 a.m. on Sept. 23, 1873.
A shower of stones scattered over an area of 3×16 miles.
Total weight about 30 pounds or 13.64 kilograms.

KHARKOV, Ukraine.
Fell at 3 p.m. on Oct. 12, 1787.
Several stones fell, but one preserved.

KHERAGUR, S. E. of Bhurtpur, Agra district, United Provinces, India.
Fell March 28, 1860.
A single small stone stated to have weighed about 1 pound.

KHETRI, Shekhawati, Jaipur, Rajputana, India.
Fell at 9 a.m. on Jan. 19, 1867.
A shower of about 40 stones which were mainly broken up by the natives and two small fragments only preserved.

KHOHAR, Banda district, United Provinces, India.
Fell at 1 p.m., Sept. 19, 1910.
A single stone, so far as known, of which some 9.7 kilograms have been preserved.

KIKINO, Vyazma, Smolensk, Russia.
Fell in 1809.
A single stone of unknown weight.

KILBOURN, Columbia County, Wisconsin.
Fell at 5 p.m. on June 16, 1911.
A single small stone of 772 grams fell upon the roof of a barn and passed through two hemlock boards. The force of the blow was quite unusual for so small a stone. (See Plate 40.)

KILLETER, County Tyrone, Ireland.
Fell at 3:30 p.m. on Apr. 29, 1844.
A shower of stones, of which but a few fragments were preserved.

KLEIN-WENDEN, Nordhausen, Erfurt, Germany.
Fell at 4:45 p.m., Sept. 16, 1843.
A single stone of about 3.25 kilograms weight.

KNYAHINYA, Nagy-Bereszna, Ungvar, Czechoslovakia.
Fell at 5 p.m. on June 9, 1866.
A shower of stones, estimated at over 1,000 in number, of a total weight of 500 kilograms; the largest single

individual, weighing 293 kilograms, penetrated the earth to the depth of 11 feet.

KRÄHENBERG, Zweibrücken, Rhenish Bavaria.
Fell at 6:30 p.m., on May 5, 1869.
A single stone of about 16.5 kilograms.

KRASNAI-UGOL, Ryazan, Russia.
Fell at 2 p.m., Sept. 9, 1829.
Seven stones, of which but two were preserved.

KULESCHOVKA, Poltava, Ukraine.
Fell at 11 a.m. on March 12, 1811.
One stone of over 6 kilograms.

KULP, Kasachsky dist., Elisavetpol, Caucasus.
Fell March 29, 1906.
Two stones of 3.5 and 7-8 kilograms.

KUSIALI, Kumaon, United Provinces, India.
Fell 5 a.m. on June 16, 1860.
One stone fell and was so badly shattered that but a few grams have been preserved.

KUTTIPPURAM, Ponnani taluk, Malabar district, Madras, India.
Fell about 7 a.m. on Apr. 6, 1914.
A shower of stones the total weight of which was about 45.5 kilograms.

KYUSHU, Japan.
Fell at 3 p.m. on Oct. 26, 1886.
A shower of stones of unknown total weight. The largest 29 kilograms.

LA BECASSE, Dun-le-Poëlier, Indre, France.
Fell at noon on Jan. 31, 1879.
A single stone of 2.8 kilograms weight.

LABOREL, Drôme, France.
Fell at 8 p.m., June 14, 1871.
Two stones of 2,091 grams.

LA CHARCA, Irapuato, Guanajuato, Mexico.
Fell at 11:30 a.m. on June 11, 1878.
A single stone of 399 grams.

La Colina, Gen. Lamadrid dept., Buenos Aires, Argentina.
Fell at 11:30 p.m., March 19, 1924.
One stone of 2 kilograms weight.

L'Aigle, Orne, France.
Fell at 1 p.m. on Apr. 26, 1803.
A shower of some 2,000 or 3,000 stones and of an aggregate weight of 37 kilograms. This fall is of historic interest, since as noted on p. 11 it served to satisfy all doubts as to the ultraterrestrial source of meteorites.

Lakangaon, Nimar, Indore, Central India.
Fell at 6 p.m. on Nov. 24, 1910.
A single stone belonging to the rare group of eukrites.
But 212.5 grams known, of which 116 are in Calcutta.

Lalitpur, Lalitpur district, United Provinces, India.
Fell at 10:30 a.m. on April 7, 1887.
A single stone which broke into pieces in falling, but 372 grams recovered.

Lance, Vendôme, Loir-et-Cher, France.
Fell at 5:20 p.m. on July 23, 1872.
A shower of stones of which half a dozen were recovered, weighing altogether 51.75 kilograms; the largest single individual weighing 47 kilograms is in the Vienna Natural History Museum.

Lançon, Bouches-du-Rhône, France.
Fell at 8:30 p.m. on June 20, 1897.
About 7 kilograms known.

Lanzenkirchen, Wiener Neustadt, Lower Austria.
Fell at 7:25 p.m., Aug. 28, 1925.
One stone weighing 5 kilograms.

Launton, Bicester, Oxfordshire, England.
Fell at 7:30 p.m. on Feb. 15, 1830.
A single stone of 1.02 kilograms.

Leeuwfontein, Pretoria, Transvaal, South Africa.
Fell at 2 p.m., June 21, 1912.
But 460 grams known.

LEIGHTON, Colbert County, Alabama.
Fell at 8 p.m., Jan. 12, 1907.
A single stone of 877 grams weight.

LEONOVKA, Novgorod-Syeversk dist., Chernigov govt., Ukraine.
Fell Aug. 23, 1900.
Two stones recorded.

LE PRESSOIR, Indre-et-Loire, France.
Fell at 3 p.m. on Jan. 25, 1845.
One stone weighing 3 kilograms, found.

LES ORMES, Yonne, France.
Fell at 5 p.m. on Oct. 1, 1857.
A single stone of about 125 grams only known.

LESVES, Namur, Belgium.
Fell at 7:30 a.m.
One stone of about 2 kilograms.

LE TEILLEUL, Manche, France.
Fell at 3 p.m., April 13, 1896.
780 grams known of which 750 grams are in the Paris Museum.

LIMERICK County, Ireland.
Fell at 9 a.m., Sept. 10, 1813.
Several stones, the 3 largest of which weighed 17, 24, and 65 pounds.

LINUM, Fehrbellin, Brandenburg, Germany.
Fell at 8 p.m. on Sept. 5, 1854.
One stone of 1,862 grams.

LISSA, Bunzlau, Bohemia.
Fell at 3:30 p.m., Sept. 3, 1808.
Four stones of a total weight of about 10.4 kilograms.

LITTLE PINEY, Pulaski County, Missouri.
Fell at 3:30 p.m. on Feb. 13, 1839.
One stone only, weighing about 22.8 kilograms.

LIXNA, Dvinsk (= Daugavpils, Dünaburg) Latvia.
Fell at 5:30 p.m. on July 12, 1820.
One stone of 40 pounds (18.14 kilograms) was recovered, the others falling in the water.

LODRAN, Multan, Punjab, India.
Fell at 2 p.m., Oct. 1, 1868.
One stone of unknown weight, about 1 kilogram preserved.
LOS MARTINEZ, Cervera, Murcia, Spain.
Fell May, 1894.
But 25 grams reported in Madrid Museum.
LUCE, Sarthe, France.
Fell at 4:30 p.m., Sept. 13, 1768.
One stone of 3.5 kilograms.
LUMPKIN, Stewart County, Georgia.
Fell at 11:45 a.m. on Oct. 6, 1869.
One stone of about 34 grams weight.
LUNDSGARD, Ljungby, Gottland, Sweden.
Fell at 8:30 p.m. on April 3, 1889.
One stone of about 11 kilograms.
LUOTOLAX, Viborg, Finland.
Fell Dec. 13, 1813.
A shower of stones falling on the surface of the ice on a lake. But few recovered.
LUPONNAS, Ain, France.
Fell at 1 p.m., Sept. 7, 1753.
Two stones weighing 5.89 kilograms. Mostly destroyed and lost.
MACAO, Rio Grande do Norte, Brazil.
Fell at 5 a.m. on Nov. 11, 1836.
A shower of stones weighing from 1 to 80 pounds each.
MADRID, Spain.
Fell at 9:30 a.m. on Feb. 10, 1896.
Several small stones weighing altogether about 400 grams.
MANBHOOM, Bengal, India.
Fell at 9 a.m. on Dec. 22, 1863.
Several stones of varying weights up to 15 kilograms, belonging to the group of amphoterites of which but 3 representatives are known.

MANEGAON, Bhusawal, East Khandesh district, Bombay, India.
Fell at 3:30 p.m. on June 29, 1843.
One stone about 5×15 inches in size which became broken in the fall and mostly lost, belonging to the rare group called diogenites by Prior.

MARIAVILLE, Rock County, Nebraska.
Fell at midnight on Oct. 16, 1898.
But 340 grams known.

MARION, Linn County, Iowa.
Fell at 2:45 p.m. on Feb. 25, 1847.
Three stones weighing 21, 20, and 40 pounds.

MARJALAHTI, Viborg, Finland.
Fell at 10 p.m. on June 1, 1902.
A single stone of about 45 kilograms which was shattered in falling.

MARMANDE, Lot-et-Garonne, France.
Fell on July 4, 1848.
Known only from fragments found in collections.

MASCOMBES, Corrèze, France.
Fell at midnight, on Jan. 31, 1835.
A single stone of about 1 kilogram weight.

MASSING, Eggenfelden, Lower Bavaria, Germany.
Fell at 10:30 a.m. on Dec. 13, 1803.
A single stone of about 1.6 kilograms of which very little was preserved.

MAUERKIRCHEN, Upper Austria.
Fell at 4 p.m. on Nov. 20, 1786.
A stone of about 18 kilograms weight.

MAURITIUS, Indian Ocean.
Fell on Dec. 22, 1801.
Three stones, weight not given, belonging to the howarditic chondrite group.

MEERUT, Meerut district, United Provinces, India.
Fell about 1860-62.
But 22 grams known.

Meester-Cornelis, Batavia, Java.
Fell between 6 and 6:15 a.m., June 2, 1915.
One stone of 24.75 kilograms weight.

Menow, Alt-Strelitz, Mecklenburg, Germany.
Fell at 12:30 p.m. on Oct. 7, 1862.
One stone of about 10.5 kilograms weight.

Mern, Praesto, Denmark.
Fell at 2:30 p.m., Aug. 29, 1878.
One stone of 4 kilograms weight.

Merua, Allahabad, United Provinces, India.
Fell at 11:15 a.m., Aug. 30, 1920.
Six stones weighing together 71.4 kilograms.

Meuselbach, Thuringia, Germany.
Fell at 7:45 p.m. on May 19, 1897.
One small stone of but 870 grams weight.

Mezö-Madaras, Transylvania.
Fell at 4:30 p.m. on Sept. 4, 1852.
A shower giving a total weight of about 22.7 kilograms, the largest weighing about 10 kilograms.

Mhow, Azamgarh district, United Provinces, India.
Fell at 3 p.m. on Feb. 16, 1827.
Four or five stones, one of which it is stated hit a man in falling. The largest weighed 1.8 kilograms.

Middlesbrough, Yorkshire, England.
Fell at 3:35 p.m. on March 14, 1881.
One stone of about 1.6 kilograms.

Mighei, Olviopol, Kherson, Ukraine.
Fell at 8:30 a.m. on June 18, 1889.
A stone the exact weight not known but represented by 8 kilograms of fragments.

Milena, Varazdin, Croatia, Yugoslavia.
Fell at 3 p.m., April 26, 1842.
Two or three stones of 5 to 6 kilograms weight.

Minnichhof, Oedenburg, Hungary.
Fell at 10:45 a.m., May 27, 1905.
One stone, weight not given.

PLATE 41

Meteoric Stone. One of the larger individuals of the fall at Modoc, Kansas, on September 2, 1905. Weight 2,268 grams

Mirzapur, Ghazipur district, United Provinces, India.
Fell at 11:30 a.m. on Jan. 7, 1910.
One stone of which two pieces weighing 208.5 grams and 8.3 kilograms were recovered.

Misshof, Courland, Latvia.
Fell at 3:30 p.m. on April 10, 1890.
One stone of about 5.8 kilograms.

Mjelleim, Hyen, Nordfjord, Norway.
Fell between 2 and 3 p.m., Jan. 24, 1898.
Probably a shower, but only a single stone found weighing about 100 grams.

Mocs, Cluj (=Klausenburg, Kolozsvar) Transylvania.
Fell at 4 p.m. on Feb. 3, 1882.
A shower of some 3,000 (estimated) stones of a total weight of 300 kilograms. The largest single individual weighed about 56 kilograms. This is one of the most widely distributed falls, portions of it at one time being found in over 100 private and public collections.

Modoc, Scott County, Kansas.
Fell at 9:30 p.m. on Sept. 2, 1905.
A fall of 15-20 stones, the largest of which weighed 4.86 kilograms, totaling about 16 kilograms. (See Plate 41.)

Mokoia, Taranaki, North Island, New Zealand.
Fell at 12:30 p.m. on Nov. 26, 1908.
Several stones of but a few pounds each and but two of which were recovered.

Molina, Murcia, Spain.
Fell on Dec. 24, 1858.
One stone of 114 kilograms weight.

Monroe, Cabarrus County, North Carolina.
Fell at 3 p.m. on Oct. 31, 1849.
One stone of about 8.64 kilograms.

Monte Milone, Macerata, Italy.
Fell at 9:15 a.m. on May 8, 1846.
Several stones of which five were recovered.

MONTLIVAULT, Loir-et-Cher, France.
Fell in the day on July 22, 1838.
One stone of but about 0.5 kilogram weight.

MOORESFORT, County Tipperary, Ireland.
Fell at noon in August, 1810.
One stone of 3.52 kilograms weight.

MORADABAD, Moradabad district, United Provinces, India.
Fell in 1808.
But about 70 grams of this fall known.

MORNANS, Bourdeaux, Drôme, France.
Fell in September, 1875.
One stone of 1.3 kilograms weight.

MOTI-KA-NAGLA, Goordha, Biana district, Bharatpur, India.
Fell at 5 p.m. on Dec. 22, 1868.
A shower of stones but only 3 found, of which the largest weighed 1.43 kilograms.

MOTTA DI CONTI, Casale, Piedmont, Italy.
Fell at 11 a.m. on Feb. 29, 1868.
Several stones of about 9.15 kilograms weight.

MOUNT BROWNE, County Evelyn, New South Wales.
Fell at 9:30 a.m. on July 17, 1902.
One stone of about 11.5 kilograms.

MUDDOOR, Mysore, India.
Fell at 7 a.m. on Sept. 21, 1865.
Two stones, one of which weighed about 2 kilograms, the second being broken in pieces.

MULLETIWU, Northern Province, Ceylon.
Fell on April 13, 1795.
A shower of which the 25 gram piece in the Paris Museum is all there is known.

MURAID, Ghatail sub-division, Mymensingh dist., Bengal, India.
Fell at 2:30 p.m., Aug. 7, 1924.
Two stones, one broken in halves, weight 4,693 grams.

Myhee Caunta, Ahmadabad, Bombay, India.
Fell at 4 p.m. on Nov. 30, 1842.
Several stones of a weight unknown.

Nagaria, Fatehabad pargana, Agra district, United Provinces, India.
Fell 1½ hours after sunrise on April 24, 1875.
One stone of about 11.8 kilograms almost wholly broken up and lost. But 20 grams preserved. A stone of more than usual interest belonging to the group of eukrites of which less than half a dozen are known.

Nagy Borové, Liptó, Czechoslovakia.
Fell on May 9, 1895.
But two small pieces known.

Nakhla, Abu Hommos, Alexandria, Egypt.
Fell at 9 a.m. on June 28, 1911.
About 40 stones totaling about 40 kilograms, of a unique stone consisting of a crystalline aggregate of olivine and diopside.

Nammianthal, South Arcot district, Madras, India.
Fell on January 27, 1886.
One stone of about 4.5 kilograms.

Nanjemoy, Charles County, Maryland.
Fell at noon on Feb. 10, 1825.
One stone of 7.5 kilograms weight and of which but 2,525 grams are known in collections.

Nann Yang Pao, southeastern Kansu, China.
Fell at 12 noon, July 11, 1917.
One stone weighing 53.2 kilograms.

Nawapali, Sambalpur district, Central Provinces, India.
Fell at 6 p.m. on June 6, 1890.
Three stones fell but only a trifle over 60 grams preserved.

Nerft, Courland, Latvia.
Fell at 4:45 a.m. on April 12, 1864.
Two stones of about 4.75 and 5.5 kilograms weight.

New Concord, Muskingum County, Ohio.
Fell at 12:45 p.m. on May 1, 1860.
A shower of some 30 stones of which the largest weighed about 47 kilograms and the total weight of which was about 500 pounds. It was from stones of this fall that was first identified and separated the new mineral merrillite.

Ngawi, Madioen, Java.
Fell at 5:15 p.m. on Oct. 3, 1883.
Two stones of about 1,303 grams weight.

Nio, west of Yamaguch, Yoshiki, Suwo, Japan.
Fell at 10:30 p.m. on Aug. 8, 1897.
Two stones weighing together 448 grams.

N'Kandhla, Zululand, Natal, South Africa.
Fell at 1:30 p.m. on Aug. 1, 1912.
One stone of about 17.3 kilograms weight.

Nobleborough, Lincoln County, Maine.
Fell at 4:30 p.m. on Aug. 7, 1823.
One stone of about 2.3 kilograms. Was badly broken and but 78 grams preserved.

Nogoya, Entre Rios, Argentina.
Fell in the evening of June 30, 1879.
One stone of about 4 kilograms.

Novy-Ergi, Novgorod govt., Russia.
Fell at 4 p.m., Dec. 10, 1662.
A shower of stones.

Novy-Projekt, Novo-Alexandrovsky dist., Kovno, Lithuania.
Fell at 2 a.m., April 25, 1908.
One stone of about 1,000 grams.

Novy-Urei, Karamzinka, Nijni-Novgorod, Russia.
Fell at 7:15 a.m. on Sept. 4, 1886.
Three stones of which some 2 kilograms have been preserved. A rare type of which but 3 are known.

NULLES, Catalonia, Spain.
Fell at 5:30 p.m. on Nov. 5, 1851.
A large number of stones reported as fallen but few preserved of which the largest weighed about 9 kilograms.

OCHANSK, Perm, Russia.
Fell at 1 p.m. on Aug. 30, 1887.
A shower of stones aggregating over 500 kilograms in weight, the largest weighing 115 kilograms.

OESEL Island, Esthonia, Baltic States.
Fell at 3:30 p.m. on May 11, 1855.
Several stones fell but only about 6 kilograms of one saved.

Ó-FEHÉRTÓ, Nyiregyhaza, Szabolcs, Hungary.
Fell on July 25, 1900.
One stone of about 3.2 kilograms weight.

OGI, Hizen, Kyushu, Japan.
Fell at 11 a.m., June 8, 1741.
Four stones fell of some 14.2 kilograms weight. Two of these were for a long time subjects of annual offerings in a temple.

OHABA, Alba Iulia (=Karlsburg), Transylvania.
Fell at 12:15 a.m. on Oct. 11, 1857.
One stone of 16.25 kilograms weight.

OKNINY, Krzemieniec, Wolyn, Poland.
Fell at 9:30 a.m. on Jan. 8, 1834.
One stone of about 12 kilograms, only a small portion of which was preserved.

OLIVA-GANDIA, Valencia, Spain.
Fell May 26, 1520.
Three stones reported to have fallen.

OLIVENZA, Badajoz, Spain.
Fell at 8 a.m., June 19, 1924.
Five stones fell of a total weight of 150 kilograms.

ORANGE RIVER, South Africa.
Fell Sept. 8, 1887.
One stone, original weight unknown and but about 8 grams known.

Orgueil, Montauban, Tarn-et-Garonne, France.
Fell at 8 p.m. on May 14, 1864.
Some 20 stones the total weight of which is not known. Some 11.5 kilograms preserved in collections. A carboniferous chondrite of more than ordinary interest. It was in this stone that was found the mineral breunnerite, the only known occurrence of a carbonate in a meteorite.

Ornans, Doubs, France.
Fell at 7:15 p.m., on July 11, 1868.
One stone of about 6 kilograms weight.

Orvinio, Rome, Italy.
Fell 5:15 a.m., Aug. 31, 1872.
Several stones from which six fragments were saved weighing 3.4 kilograms.

Otomi, Yamagata, Japan.
Fell May 24, 1867.
One stone of 6.5 kilograms weight.

Ottawa, Franklin County, Kansas.
Fell at 6:15 p.m. on April 9, 1896.
One stone of 840 grams weight.

Oviedo, Asturias, Spain.
Fell at 5:45 p.m. on August 5, 1856.
Three fragments weighing 205 grams are all that is known of this fall.

Pacula, Jacala, Hidalgo, Mexico.
Fell the morning of June 18, 1881.
5.4 kilograms known of this stone.

Palahatchie, Rankin County, Mississippi.
Fell Oct. 17, 1910.
One small stone, weight not given.

Pampanga, Philippine Islands.
Fell on April 4, 1859.
One stone, original weight not known, but 165 grams accounted for in the collections.

PARNALLEE, Madura district, Madras, India.
Fell at noon, Feb. 28, 1857.
Two stones of about 17 and 61 kilograms.

PAVLOGRAD, Ekaterinoslav, Ukraine.
Fell May 19, 1826.
One stone of 40 kilograms weight.

PAVLOVKA, Balashey, Saratov, Russia.
Fell at 5 p.m. on Aug. 2, 1882.
One stone of 2 kilograms weight.

PERAMIHO, Ungoni, Tanganyika Territory, East Africa.
Fell at 7 a.m. on Oct. 24, 1899.
One stone of 165 grams weight.

PERTH, SCOTLAND.
Fell at 12:30 p.m. on May 17, 1830.
A stone said to have been 7 inches in diameter fell, but only two small pieces weighing about 2 grams preserved.

PETERSBURG, Lincoln County, Tennessee.
Fell at 5:30 p.m. on Aug. 5, 1855.
One stone of about 1.8 kilograms weight.

PHU-HONG, Binh-Chanh, Cochin China.
Fell on Sept. 22, 1887.
One small stone of but about 500 grams weight.

PILLISTFER, Livonia, Latvia.
Fell at 12:30 p.m. on Aug. 8, 1863.
Four stones found weighing about 23.25 kilograms.

PIRGUNJE, Dinajpur district, Bengal, India.
Fell on Aug. 29, 1882.
One stone of 842 grams weight.

PIRTHALLA, Hissar district, Punjab, India.
Fell at 2:30 p.m. on Feb. 9, 1884.
One stone of about 1.36 kilograms weight.

PLOSCHKOVITZ, Litomerice, Bohemia.
Fell at 2 p.m., June 22, 1723.
A shower of 33 stones of which but a single piece, 1¼ ounces, is known with certainty.

PNOMPEHN, Cambodia, French Indo-China.
Fell at 3 p.m., June 20-23, 1868.
Three stones of one of which but 41 grams are preserved.

POHLITZ, Gera, Reuss, Germany.
Fell at 8 a.m., Oct. 13, 1819.
One stone of about 3 kilograms weight.

POKHRA, Basti district, Gorakhpur, United Provinces, India.
Fell at 8:30 p.m., May 27, 1866.
One stone of but 350 grams weight.

PONTA GROSSA, Paraná, Brazil.
Fell in April, 1846.
One stone of 667 grams weight.

PORTUGAL.
Fell Feb. 19, 1796.
One stone of about 4.5 kilograms.

PRICETOWN, Highland County, Ohio.
Fell Feb. 13, 1893.
One stone of but 900 grams weight.

PULSORA, Ratlam State, Central India.
Fell in the afternoon on March 16, 1863.
One stone weighing 680 grams.

PULTUSK, Warsaw, Poland.
Fell at 7 p.m. on Jan. 30, 1868.
A shower of stones estimated at over 100,000 pieces of which the largest weighed 9 kilograms. One of the most remarkable falls on record. Over 200 kilograms are listed as scattered throughout the various collections of the world.

QUEENS MERCY, Matatiele, Griqualand, East, Cape Province, South Africa.
Fell at 8 p.m., April 30, 1925.
Three stones, one large, total weight unknown.

QUENGGOUK, Bassein district, Lower Burma.
Fell at 2:30 a.m. on Dec. 27, 1857.
Three fragments belonging to the same mass fell weighing respectively 2,291, 1,909½, and 1,844½ grams.

QUINCAY, Vienne, France.
Fell in the summer of 1851.
Nothing known of the fall and but 31 grams recorded in collections.

RAKOVKA, Tula, Russia.
Fell at 3 p.m. on Nov. 20, 1878.
One stone "about as large as a man's head." Weight not given.

RAMPURHAT, Birbhum dist., Bengal, India.
Fell at 9:30 a.m., Nov. 21, 1916.
One stone of 100 grams weight.

RANCHAPAR, Jamtara, Santhal, Bihar, India.
Fell at 8:30 on Feb. 20, 1917.
Four pieces weighing altogether 366.3 grams.

RANCHO DE LA PRESA, Zenapecuaro, Michoacan, Mexico.
Fell in 1899.
But 3 grams known.

RENAZZO, Cento, Ferrara, Italy.
Fell at 8:30 p.m. on Jan. 15, 1824.
Several stones fell, three being recovered, the largest of which weighed 5 kilograms.

RICHARDTON, Stark County, North Dakota.
Fell at 10 p.m. on June 30, 1918.
Several stones of a total weight of about 90.9 kilograms.

RICHMOND, Chesterfield County, Virginia.
Fell at 8:30 a.m. on June 4, 1828.
One stone of about 18.2 kilograms.

RICH MOUNTAIN, Jackson County, North Carolina.
Fell at 2 p.m. on June 30, 1903.
But one fragment weighing 668 grams found.

ROCHESTER, Fulton County, Indiana.
Fell at 8:45 p.m. on Dec. 21, 1876.
An unusually spectacular display over an area of over 1,000 miles yielded but one small stone of about 340 grams weight.

Rose City, Ogemaw County, Michigan.
Fell at 11 p.m., Oct. 17, 1921.
Three stones; total weight 10.5 kilograms.

Rowton, Wellington, Shropshire, England.
Fell at 3:45 p.m. on April 20, 1876.
One stone weighing 3.41 kilograms.

Ruschany, Slonim, Grodno, Poland.
Fell on Dec. 7, 1894. (?).
Fall reported, none of the material extant.

Ryechki, Sumy district, Kharkov, Ukraine.
Fell at 1:30 p.m. on April 9, 1914.
Two stones of 3.41 and 2.5 kilograms.

Sabetmahet, near Balrampur, Gonda district, United Provinces, India.
Fell in the evening of Aug. 16, 1885.
A stone of about 2 kilograms weight fell and was made an object of worship. But 3 grams were secured and preserved in the Calcutta Museum.

St. Caprais-de-Quinsac, Gironde, France.
Fell at 2:45 p.m. on Jan. 28, 1883.
One stone of 282½ grams weight.

St. Christophe-la-Chartreuse, Roche-Servière, Vendée, France.
Fell on Nov. 5, 1841.
One stone of about 5½ kilograms.

St. Denis-Westrem, Ghent, Belgium.
Fell at 7:45 p.m. on June 7, 1855.
One stone of but 700 grams weight.

St. Germain-en-Puel, Vitre, Ille-et-Vilaine, France.
Fell at 3:30 p.m. on July 4, 1890.
One stone of about 4 kilograms.

St. Mark's Mission Station, Transkei, Cape Province, South Africa.
Fell at 11 p.m. on Jan. 3, 1903.
One stone of 13.78 kilograms weight.

St. Mesmin, Aube, France.
Fell at 3:45 p.m. on May 30, 1866.
Three stones fell weighing 1.9, 2.2, and 4.2 kilograms respectively.

St. Michel, Finland.
Fell at 7:25 p.m. on July 12, 1910.
Two stones of 7 and 10 kilograms weight respectively.

Salles, Villefranche, Rhone, France.
Fell at 6 p.m. on March 12, 1798.
One stone of about 91 kilograms.

Santa Barbara, Rio Grande, Brazil.
Fell on Sept. 26, 1873.
One stone of about 400 grams.

Santa Isabel, Santa Fé Province, Argentina.
Fell at 9:30 a.m., Nov. 18, 1924.
One stone, weight 5.5 kilograms.

Saratov govt., Russia.
Fell between 4 and 6 p.m., Sept. 11, 1918.
Several stones of total weight of 328 kilograms.

Sauguis, St. Étienne, Basses-Pyrénées, France.
Fell at 2:30 a.m. on Sept. 7, 1868.
One stone from which 2-4 kilograms were preserved.
Total weight unknown.

Sauveur, Haute-Garonne, France.
Fell July, 10, 1914.
One stone of about 14 kilograms.

Savtschenskoje, Tiraspol, Kherson, Ukraine.
Fell at 8 p.m. on July 27, 1894.
One stone of about 2.5 kilograms.

Schellin, Stargard, Pomerania, Prussia.
Fell at 4 p.m. on April 11, 1715.
Two stones, the larger weighing 7 kilograms. But 348 grams preserved.

Schonenberg, Pfaffenhausen, Swabia, Bavaria.
Fell at 2 p.m. on Dec. 25, 1846.
One stone of about 8 kilograms weight.

SEARSMONT, Waldo County, Maine.
Fell at 8:15 a.m. on May 21, 1871.
One stone which broke by impact with ground; original weight about 5.45 kilograms. Only about 1 kilogram preserved which has been scattered through 27 collections in fragments of from 1 to 60 grams, the National collections containing the larger portion in the form of 3 pieces weighing 94.55 grams. The main mass of all, 900 grams weight, is in the museum of Amherst College.

SEGOWLIE, Bettiah, Champaran district, Bihar, India.
Fell at noon on March 6, 1853.
A shower of some 30 stones varying in weights up to 6.5 kilograms.

SENA, Sariñena, Huesca, Spain.
Fell at midnight on Nov. 17, 1773.
One stone of about 4 kilograms.

SERES, Macedonia.
Fell in June, 1818.
One stone of about 8.5 kilograms.

SERRA DE MAGE, Pesqueira, Pernambuco, Brazil.
Fell at 11 a.m. on Oct. 1, 1923.
A shower of stones of which some 50 were recovered. Weight not given.

SETE LAGOAS, Minas Geraes, Brazil.
Fell Dec. 15, 1908.
Six small stones, weight not given.

SEVILLA, Andalusia, Spain.
Fell on Nov. 1, 1862.
One stone of 100 grams weight.

SEVRUKOVO, Byelgorod, Kursk, Russia.
Fell at 11:45 p.m. on May 11, 1874.
One large stone of 98 kilograms weight.

SHALKA, Bishnupur, Bankrura district, Bengal, India.
Fell at 4:30 p.m. on Nov. 30, 1850.
A large stone said to have measured 3 feet in diameter fell and was broken in pieces by the impact and only

about 36.25 kilograms preserved. The stone belongs to the rare group of diogenites of Prior, and pieces have been eagerly sought by collectors, causing it to be broken and scattered through some 30 collections in bits from mere splinters to a mass of 1.9 kilograms which remains in the Calcutta Museum.

SHARPS, Richmond County, Virginia.
Fell April 1, 1921.
One stone of 1,265 grams weight.

SHELBURNE, Grey County, Ontario, Canada.
Fell at 8 p.m. on Aug. 13, 1904.
Two stones weighing 5.91 and 12.72 kilograms.

SHERGHOTTY, Gya, Bihar, India.
Fell at 9 a.m. on Aug. 25, 1865.
One stone of 5 kilograms.

SHIKARPUR, Purnea dist., Bihar and Orissa prov., India.
Fell at 9 a.m., Aug. 9, 1921.
One stone of about 3,680 grams.

SHUPIYAN, Kashmir, India.
Fell in April, 1912.
Two stones of 0.5 and 4.5 kilograms.

SHYTAL, Madhupur jungle, Mymensingh dist., Bengal, India.
Fell at noon on Aug. 11, 1863.
One stone of about 3.2 kilograms.

SIENA, Tuscany, Italy.
Fell at 7 p.m. on June 16, 1794.
A shower of small stones the largest weighing but about 3.5 kilograms.

SIMMERN, Hunsrück, Rhenish Prussia.
Fell at 9:15 a.m. on July 1, 1920.
A large number of stones scattered over an area of 2×10 miles. But 3 were found weighing 142, 470, and 610 grams respectively.

SIMONOD, Ain, France.
Fell at 9 p.m. on Nov. 13, 1835.
One stone, weight unknown.

Sinai Peninsula, Egypt.
Fell at 2:30 p.m. on July 14-17, 1916.
Two stones reported to have fallen of which but one, weighing 1,455 grams, was preserved.

Sindhri, Khipro taluk, Thar and Parker dists., Bombay, India.
Fell at 11 p.m. on June 10, 1901.
Two stones, one of less than 2 kilograms weight and the other of about 6.6 kilograms.

Sitathali, Raipur dist., Central Provinces, India.
Fell at 11 a.m. on March 4, 1875.
Two stones of total weight of 1.15 kilograms.

Ski, Akershuus, Christiania, Norway.
Fell in the evening of Dec. 27, 1848.
One small stone weighing 850 grams.

Slavetic, Zagreb, Croatia, Yugoslavia.
Fell at 10:30 a.m. on May 22, 1868.
Several stones that were said to have fallen, but two preserved weighing 1,708 grams.

Slobodka, Yukhnov, Smolensk, Russia.
Fell on Aug. 10, 1818.
One stone of about 2.75 kilograms weight.

Soko-Banja, Aleksinac, Serbia.
Fell at 2 p.m. on Oct. 13, 1877.
Some 10 stones found scattered over an area 7×1 miles and weighing altogether about 80 kilograms.

Sone, Shuchi, Funai, Tamba, Japan.
Fell at noon on June 7, 1866.
One stone of 17 kilograms weight.

Stalldalen, Nya Kopparberg, Orebro, Sweden.
Fell at 11:30 p.m., June 28, 1876.
Eleven stones of a total weight of about 34 kilograms, the largest weighing about 12.5 kilograms.

Stannern, Iglau, Moravia, Czechoslovakia.
Fell at 6 a.m. on May 22, 1808.
A shower of 200-300 stones mostly small and of a total weight of about 52 grams. It belongs to the rare

class of eukrites and has been the subject of many papers and is broken and scattered throughout nearly 100 collections.

STAVROPOL, north side of the Caucasus, Russia.
Fell at 5 p.m. on March 24, 1857.
One stone weighing about 1.5 kilograms.

STRATHMORE, Perthshire, Scotland.
Fell at 1.15 p.m. on Dec. 3, 1917.
Four stones fell weighing all told 13.41 kilograms.

SULTANPUR, Ballia dist., United Provinces, India.
Fell at 11 a.m., July 10, 1916.
Several stones of a total weight of 1,710 grams.

SUPUHEE, Padrauna, Gorakhpur dist. United Provinces, India.
Fell at noon on Jan. 19, 1865.
Six stones fell, but 5 preserved weighing about 7 kilograms.

TABOR, Bohemia.
Fell at 8 p.m. on July 3, 1753.
A shower of many stones the largest weighing about 6 kilograms.

TADJERA, Sétif, Constantine, Algeria.
Fell at 10:30 p.m. on June 9, 1867.
Two stones of 3 and 6 kilograms (est.) respectively. Of particular interest on account of black color which Meunier considers due to heating.

TAKENOUCHI, Yabu, Tajima, Japan.
Fell at 5:30 a.m. on Feb. 18, 1880.
One stone of about 750 grams.

TANE, Lake Biwa, Shiga, Omi, Japan.
Fell at 2:28 p.m. on Jan. 25, 1918.
One stone of 311 grams.

TENNASILM, Esthonia, Baltic States.
Fell at noon on June 28, 1872.
One stone of about 28.5 kilograms.

TIESCHITZ, Prerov, Moravia, Czechoslovakia.
Fell at 1:45 p.m. on July 15, 1878.
One stone of 28 kilograms weight.

Timochin, Yukhnov, Smolensk, Russia.
Fell at 3 p.m. on March 25, 1807.
One stone of 65.5 kilograms weight.

Tjabé, Padang, Rembang, Java.
Fell at 9 p.m. on Sept. 19, 1869.
A stone of 20 kilograms.

Tjerebon, Java.
Fell at 10:30 p.m., July 10, 1922.
Two stones weighing 16.5 kilograms.

Tomakovka, Ekaterinoslav, Ukraine.
Fell at 9:30 p.m. on Jan. 17, 1905.
Several small stones. Total weight not given.

Tomatlan, Jalisco, Mexico.
Fell at 4:30 p.m. on Sept. 17, 1879.
Two or three stones, the largest weighing less than a kilogram.

Tonk, Rajputana, India.
Fell at 3:55 p.m. on Jan. 22, 1911.
A shower of small stones of which only 7.7 grams were collected.

Toulouse, Haute Garonne, France.
Fell at 8 p.m. on April 10, 1812.
A small shower eight of which were found, the largest weighing about 1 kilogram.

Tounkin, Tunka, Irkutsk, Siberia.
Fell at 7 a.m., Feb. 18, 1824.
One stone of about 2 kilograms.

Tourinnes-la-Grosse, Tirelmont, Belgium.
Fell at 11:30 a.m., Dec. 7, 1863.
Two stones, one of 7 and one of 7.5 kilograms weight.

Trenzano, Brescia, Italy.
Fell at 4 p.m., Nov. 12, 1856.
Three stones said to have fallen but two found, the largest weighing 9 kilograms.

Treysa, Hesse, Germany.
Fell at 3:30 p.m., April 3, 1916.
One stone of 63 kilograms weight.

Troup, Smith County, Texas.
Fell on the morning of April 26, 1917.
One stone of about 1 kilogram weight.

Tuan Tuc, Cochin China.
Fell at 3 p.m., June 30, 1921.
Four stones fell, total weight not given.

Tysnes Island, Hardanger Fiord, Norway.
Fell at 8:30 p.m., May 20, 1884.
Two stones, the larger weighing 18.95 kilograms and the smaller but 910 grams.

Uberaba, Minas Geraes, Brazil.
Fell at 10 a.m., June 29, 1903.
One stone of 30-40 kilograms.

Uden, North Brabant, Holland.
Fell at 10:30 a.m., June 12, 1840.
One stone of but 710 grams weight.

Udipi, South Kanara district, Madras, India.
Fell at 10 a.m., April, 1866.
One stone of about 3.63 kilograms.

Umbala, Punjab, India.
Fell 1822-3.
One stone of about 100 grams.

Utrecht, Holland.
Fell at 8 p.m., June 2, 1843.
Two stones weighing 2.7 and 7 kilograms.

Vago, Verona, Italy.
Fell on June 21, 1668.
A shower of doubtful authenticity.

Valdinizza, Pavia, Italy.
Fell at 10 a.m., July 12, 1903.
One stone of 131 grams weight.

Vavilovka, Kherson, Ukraine.
Fell at 2 p.m., June 19, 1876.
One stone of about 16 kilograms weight, belonging to the rare group of amphoterites.

Verkhne Tschirskaia, Region of Don Cossacks, Russia.
Fell at midday, Nov. 12, 1843.
One stone of about 8 kilograms weight.
Vernon County, Wisconsin.
Fell at 9 a.m., March 26, 1865.
Two stones of 700 and 800 grams weight.
Vigarano, Ferrara, Italy.
Fell at 9:30 p.m., Jan. 22, 1910.
Two stones of about 4.5 and 11.5 kilograms weight.
Villarrira, Paraguay.
Fell at 7 p.m., July 20, 1925.
One stone, weight not given.
Virba, Vidin, Bulgaria.
Fell on June 1, 1873.
One stone of 3.6 kilograms weight.
Vishnupur, Bankura district, Bengal, India.
Fell at 9:30 a.m., Dec. 15, 1906.
Two stones of 670 and 1767 grams weight.
Visuni, Umarkot, Thar and Parkar dist., Sind, India.
Fell at noon, Jan. 19, 1915.
One stone of 594 grams weight.
Vouillé, Poitiers, Vienne, France.
Fell at 11 p.m., May 13, 1831.
One stone of about 20 kilograms weight.
Walkringen, Bern, Switzerland.
Fell between 7 and 8 p.m., May 18, 1698.
One stone, no further record.
Warrenton, Warren County, Missouri.
Fell at 7:15 a.m., Jan. 3, 1877.
One stone estimated to have weighed about 100 pounds but of which only about 1,600 grams are known.
Wessely, Hradisch, Moravia, Czechoslovakia.
Fell at 3:30 p.m., Sept. 9, 1831.
One stone of about 3.75 kilograms weight.
Weston, Fairfield County, Connecticut.
Fell at 6:30 a.m., Dec. 14, 1807.

Several stones of an estimated total weight of 330 pounds but largely broken up and lost. Of interest as being the first stone to have been observed to fall and to have been described in America.

WITKLIP, Carolina district, Transvaal, South Africa.
Fell at 9:40 a.m., May 26, 1918.
One stone fell, but of this but four fragments weighing altogether but 22 grams preserved.

WITTEKRANTZ, Beaufort West, Cape Province, South Africa.
Fell at 8 a.m., Dec. 9, 1880.
Two stones, the larger weighing about 2 kilograms.

WOLD COTTAGE, Thwing, Scarborough, Yorkshire, England.
Fell at 3:30 p.m., Dec. 13, 1795.
One stone of about 25.5 kilograms weight.

YATOOR, Nellore, Madras, India.
Fell at 4:30 p.m., Jan. 23, 1852.
One stone of about 13.6 kilograms weight.

YONOZU, Nishikambara, Echigo, Japan.
Fell at 4 p.m., July 14, 1837.
A stone of about 13.5 kilograms weight.

ZABORZIKA, Jitomir, Volhynia, Ukraine.
Fell April 11, 1818.
One stone of about 21 kilograms.

ZABRODJE, Vilna, Lithuania.
Fell 2 hours before sunset, Sept. 22, 1893.
One stone of about 3 kilograms fell through the roof of a house.

ZAVID, Zvornik, Bosnia, Yugoslavia.
Fell at 11:30 a.m., Aug. 1, 1897.
Four stones weighing 48 and 220 grams, and 2.5 and 90 kilograms.

ZEBRAK, Horovice (= Horowitz) Beraun, Bohemia.
Fell at 8 a.m., Oct. 14, 1824.
One stone of about 2 kilograms.

ZMENJ, Minsk, Russia.
Fell in August of 1858.
One stone of but 246 grams.

ZOMBA, Myasaland, British Central Africa.
Fell at 7:45 a.m., Jan. 25, 1899.
Several stones found scattered over an area of 3×9 miles, the largest weighing about 2.27 kilograms; total weight about 7.5 kilograms.

ZSADANY, Temes district, Rumania.
Fell between 3 and 4 p.m., March 31, 1875.
A shower of which but 9 small stones were recovered of a total weight of 552 grams.

II. STONY IRONS

Out of the score or more of stony irons variously classed as lodranites, mesosiderites, siderophyrs, and pallasites, but five were seen to fall. These are as follows:

BAREA, Logroño, Spain.
Fell July 4, 1842.
A mass of about 32 kilograms weight, belonging to the group of mesosiderites.

ESTHERVILLE, Emmet County, Iowa.
Fell at 5 p.m. on May 10, 1879.
A shower of several large and hundreds of small fragments totaling not less than 318.2 kilograms, the larger of which weighed some 68 and 153.2 kilograms. One of the most interesting of its class.

LODRAN, Multan, Punjab, India.
Fell at 2 p.m. on Oct. 1, 1868.
A stony iron of exceptional interest of which the original weight is not known and of which but 970 grams are preserved. It stands by itself in the class of *lodranites*.

MARJALAHTI, Viborg, Finland.
Fell at 10 p.m. on June 1, 1902.
One individual, a pallasite, weighing about 45 kilograms.

VERAMIN, Karand, Tehran, Persia.
Fell 3 hours before sunset in May, 1880.
An interesting mass of about 54 kilograms weight preserved in the palace of the Shah of Persia and from

which H. A. Ward secured the privilege of cutting away some 2 kilograms for other collections.

III. IRONS

Of the 350 known all-metal meteorites but 22 were seen to fall. These are as follows:

AVCE, Isonzo Valley, Gorizia, Italy.
Fell at 8:45 a.m., March 31, 1908.
A mass of but 1,230 grams fell.

BEZERROS, Pernambuco, Brazil.
Fell May 9, 1915.
A mass the original weight of which is given as 20 tons (18,181 kilograms).

BOGUSLAVKA, 220 km. north of Vladivostok, Siberia.
Fell at 11:47 a.m., Oct. 18, 1916.
Two masses of 57 and 199 kilograms respectively.

BRAUNAU, Trutnov, Bohemia.
Fell at 3:45 a.m., July 14, 1847.
Two masses of 17 and 22 kilograms.

CABIN CREEK, Johnson County, Arkansas.
Fell at 3 p.m., March 27, 1886.
A mass of 107 pounds (48.7 kilograms).

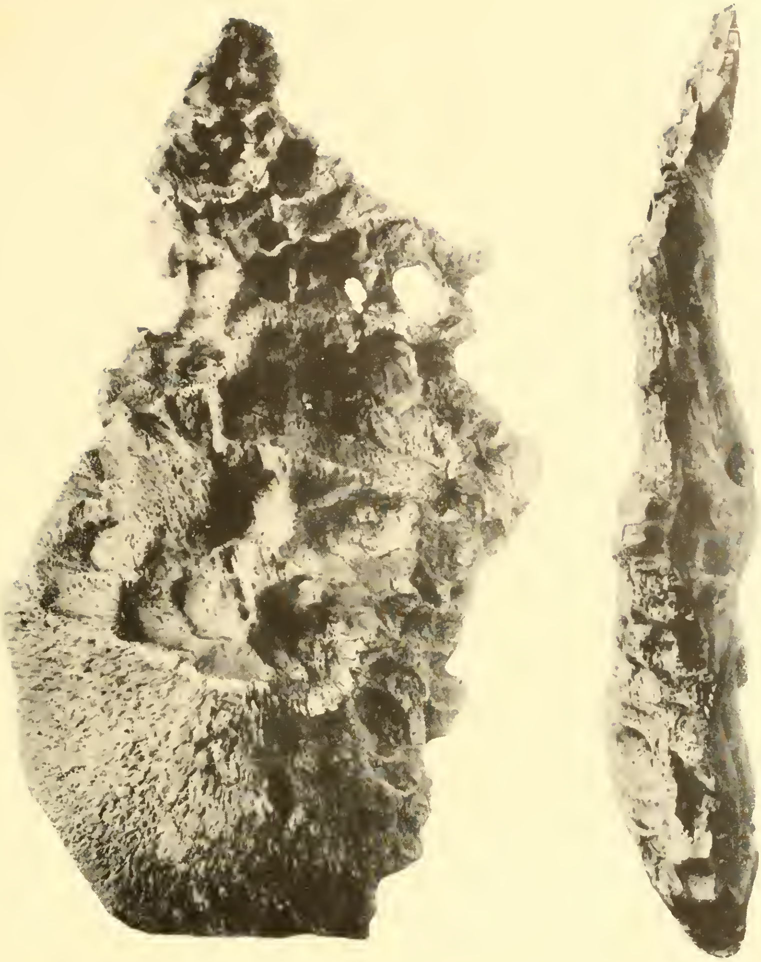
CHARLOTTE, Dickson County, Tennessee.
Fell between 2 and 3 p.m., July 31 or Aug. 1, 1835.
A mass of about 4 kilograms.

GARHI YASIN, Shikarpur taluk, Sukkur dist., Bombay, India.
Fell at night time in January, 1917.
A small mass of but 380 grams.

HRASCHINA, Zagreb (-Agram) Croatia, Yugoslavia.
Fell at 6 p.m., May 26, 1751.
Two masses of 9 and 40 kilograms weight.

MARIAVILLE, Rock County, Nebraska.
Fell at midnight on Oct. 16, 1898.
A small mass of but 340 grams weight. Perhaps doubtful.

MAZAPIL, Zacatecas, Mexico.
Fell at 9 p.m. on Nov. 27, 1885.
One of the most interesting falls on record on account of the details gathered. Fell during a star shower period and is thought possibly from Biela's Comet.
NEDAGOLLA, Vizagapatam district, Madras, India.
Fell at 7 p.m., Jan. 23, 1870.
A single mass of about 4½ kilograms.
N'GOUREMA, Jenne, Massina, French West Africa.
Fell June 15, 1900.
A mass of about 37.5 kilograms belongs to the rare group of brecciated octahedrites. (See Plate 42.)
N'Kandhla, Zululand, Natal South Africa.
Fell at 1:30 p.m., Aug. 1, 1912.
A mass of about 17.2 kilograms weight.
NORFOLK, Montgomery County, Virginia.
Fell in September of 1907.
A mass of 23 kilograms weight.
OKANO, Sasayama, Tamba, Japan.
Fell at 6:35 a.m., April 7, 1904.
A mass of 4,742 grams weight.
PITTS, Wilcox County, Georgia.
Fell at 9 a.m., April 20, 1921.
Four pieces classed as octahedrites with silicate inclusions and weighing about 4 kilograms.
QUESA, Enguera, Valencia, Spain.
Fell at 9 p.m., Aug. 1, 1898.
A mass of about 10.75 kilograms weight.
ROWTON, Wellington, Shropshire, England.
Fell at 3:45 p.m., April 20, 1876.
A mass of about 3.4 kilograms.
SAMELIA, Shahpura, Rajputana, India.
Fell at 5:30 p.m., May 20, 1921.
Three masses of total weight 2,461 grams.
TREYSA, Hesse, Germany.
Fell at 3:30 p.m., April 3, 1916.
A mass of 63 kilograms weight.



1 2

(1) Front and (2) side views of an iron meteorite that fell at N'Gourema, Africa, on June 15, 1900. It is of unusual interest on account of its shape and being one of the 22 irons seen to fall

Victoria West, Cape Province, South Africa.
Fell 1860.
A mass of about 3 kilograms.

Winburg, Orange Free State, South Africa.
Fell 1881.
A mass of about 50 kilograms.