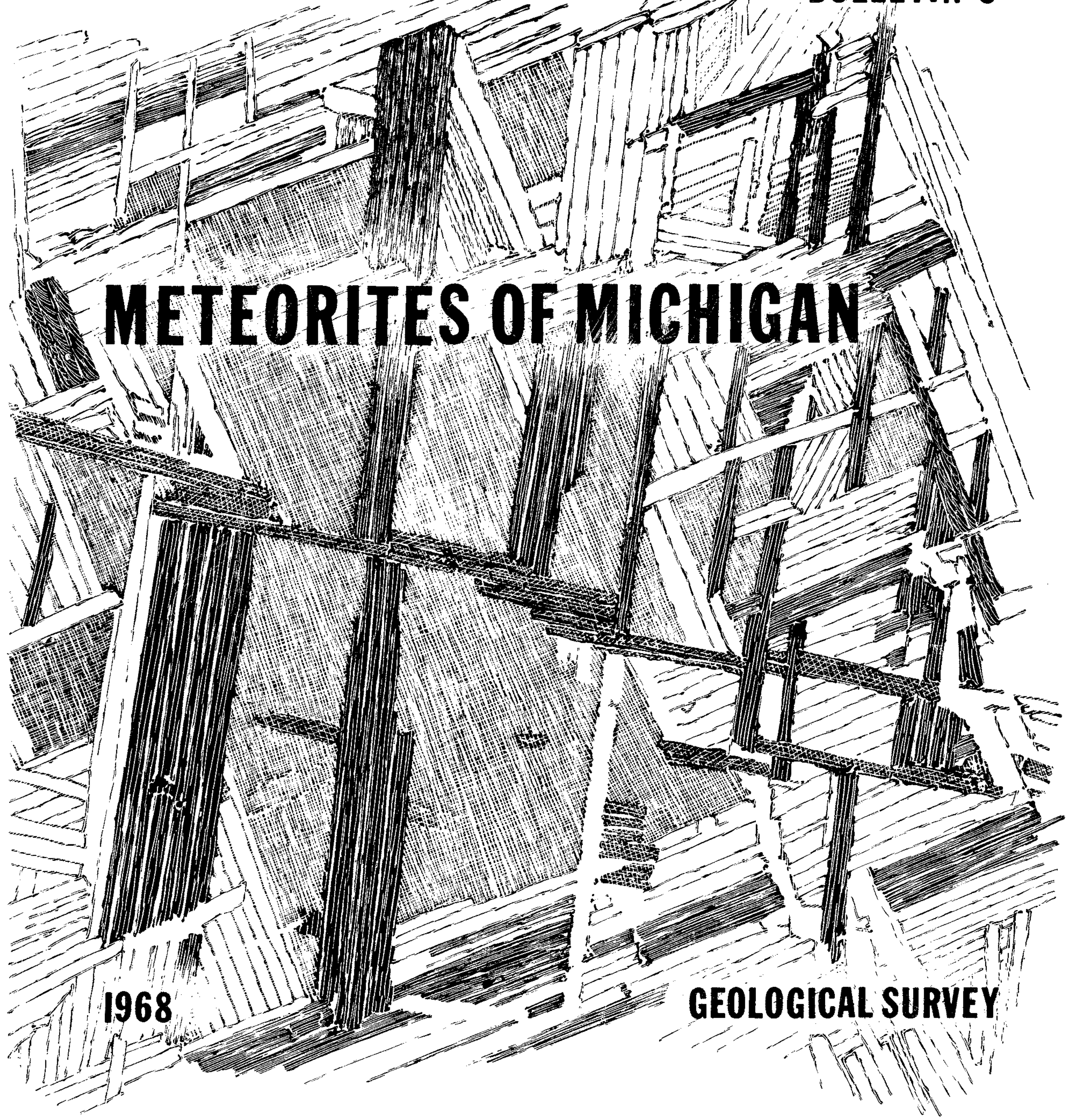
BULLETIN 5

METEORITES OF MICHIGAN



1968

GEOLOGICAL SURVEY

GLOSSARY

Mineral terms are defined in Mineralogy chapter.

ablation: Removal of material from a solid object through vaporization.

achondrite: Type of stony meteorite lacking the chondrules characteristic of most stony meteorites.

aerolite: Another name for stony meteorite.

ataxite: An iron meteorite consisting of either pure kamacite, an irregular mixture of kamacite and taenite, or pure taenite.

bolide: Exploding fireball.

chondrite: Stony meteorite containing chondrules.

chondrule: Small nearly spherical aggregate of the minerals olivine and/or pyroxene found in large numbers in most stony meteorites. They are usually less than ⅛ inch in diameter.

end-point: The point where a fireball disappears, often in a shower of "sparks".

etch: To corrode a prepared surface with acid for the purpose of revealing structural details.

fireball: Very bright meteor.

fusion crust: The outer covering of a meteorite produced by solidification of melted surface materials formed as a meteorite passes through the atmosphere.

hexahedrite: Iron meteorite consisting of large cubic crystals of kamacite.

mesosiderite: Stony-iron meteorite, the stony portion of which consists of the pyroxene and plagioclase minerals.

meteor: The light phenomenon produced by a solid body moving very rapidly through the atmosphere. Popularly called a "shooting star".

(continued inside rear cover)

Geological Survey

BULLETIN 5

METEORITES OF MICHIGAN

by

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Michigan Department of Conservation

Lansing, 1968

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DEPARTMENT OF CONSERVATION

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GEOLOGICAL SURVEY DIVISION

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Foreword

This booklet explains the basic "why's" and "wherefore's" of some of the most unique rock and mineral specimens found on earth. Although intended primarily for persons having little acquaintance with meteorites, this information will interest most anyone who wonders how these small astronomical bodies are identified, how they originated, and how many and what types have been reported in Michigan. Readers wishing to delve further into the subject should consult the reading list in back. Those wishing to skip the short technical chapter on mineralogy may do so without loss of continuity.

Meteorites are found by people, wherever people happen to be. Although most anyone could find a "wanderer from the sky", the actual possibility is slight because these are among the rarest of all mineral objects. Our knowledge of them, therefore, depends to a great extent upon the willingness of finders to make specimens available for study and display. This book is dedicated to those individuals who have contributed to the finding and preserving of specimens in Michigan.

Mr. Chamberlain is Acting Director in the Abrams Planetarium at Michigan State University. Meteors and meteorites have been a special concern of his for a number of years. Since coming to Michigan he has been particularly active in promoting a better understanding of these extraordinary events, particularly as they relate to our own area.

GERALD E. EDDY
State Geologist
Michigan Geological Survey

Lansing
Nov. 1, 1967

ILLUSTRATIONS

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Outstanding photograph of September 17, 1966 fireball taken at Hamilton, Ontario by professional photographer James C. Fish.

I

FIRE IN THE SKY

A traveler is suddenly dazed by a brilliant streak of light; a pedestrian stops and turns his eyes upward in complete amazement; two lovers turn their attention toward the heavens; an astronomer in an observatory catches a glimpse of a brilliant fireball. A remarkable event has transpired! Each saw the same phenomenon, and each remembered it slightly differently. Some were frightened, others astonished; a few understood what it was—two worlds colliding in space.

On December 9, 1965 at about 4:43 p.m. E. S. T. shortly before sunset, people were engaged in their usual pursuits, but for some the routine was momentarily interrupted by a most exciting event—a brilliant ball of fire, rocketing through the daylight sky. Even though lasting only a few seconds, people in seven states and a section of Canada saw it. Those facing the right direction and having a clear view saw it best. Others had their attention prompted by a startled exclamation: "look", or by a bright reflection off a window. Some reported their shadow appeared faintly before them, then turned to look skyward.

That evening the news media carried a variety of stories: airplanes were reported down, rocket and missile firings supposedly went astray, and "UFO's" were about again. One astronomer attributed the occurrence to reentry of an earth satellite. Others called attention to the Geminide meteor shower then going on. Persons acquainted with meteorite falls were not confused—they knew a meteorite had collided with the earth.

Witnesses described a brilliant, almost blinding, white light changing to yellow or orange before disappearing. Lasting only 4 seconds, the fireball brightened at one or more points and finally burst and disappeared leaving a trail of "smoke" along the final portion of its path. Although disipating considerably in a few minutes, the trail remained visible for about an hour. Few observers realized that an object from space had plummeted into the earth's blanket of air.

But where did the meteorite fall? Early newspaper reports indicated something had fallen near Pittsburgh, Pennsylvania, and officials had isolated a wooded area and were searching for a smoldering object. In Lorain County, Ohio, brush fires were attributed to the bolide, or exploding fireball. In Battle Creek, Michigan, a woman claimed to possess a stone fragment from the fireball. In Jackson, Michigan, a young boy saw the fireball and reported quickly finding a steaming hot stone which remained warm for several hours. Other objects found in Livonia, Michigan, and Elyria, Ohio, and elsewhere, were supposedly associated with the event. Doubtless some people believe they possess part of the meteorite. Observers in several states were certain the object landed within a mile from them. Several insisted they could go right to the spot where it landed.

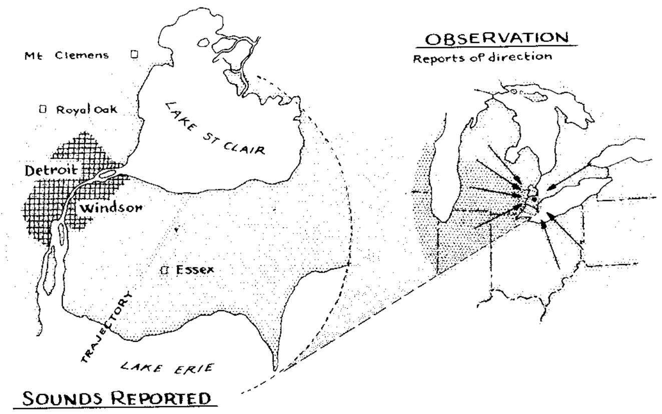


Figure 1. Region of visibility of the fireball of December 9, 1965. Early reports indicated that the fireball ended over ground in southwestern Ontario as shown by the arrows. On the left is the region where thunderous sounds were reported following the fireball.

Despite all this confusion, the trajectory could be determined and the approximate fall area located. Unless the observer is literally in the fall area, the actual spot cannot be located from a single observation. As a matter of fact, people in the fall area usually see little more than a flash of light filling the sky. After the flash they hear tremendous sounds. On the other hand, observers well beyond the range of these sounds, a hundred miles or more, see the meteor shooting toward the horizon, appearing to drop nearby. Individuals often report: "it definitely went between me and those nearby trees." Indeed, any bright moving object in the sky will seem to do so, especially when trees are bare.

An estimate of the flight path, or trajectory, can be derived from at least two good observations from widely separated places. Numerous sightings over a wide area allow a more accurate plot. The author and his colleagues documented the December 9, 1965 fireball in Vol. 61, August, 1967 of the Journal of the Royal Astronomical Society of Canada. A summary of the procedure follows.

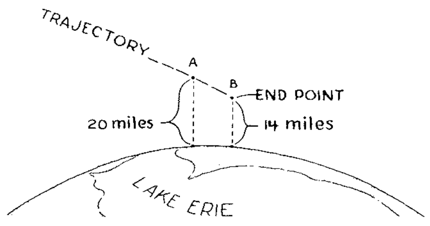
The news media were alerted that a meteorite had fallen, and that observations were desired. A map of the eastern United States was readied for plotting end-points reported from various locations. The end-point is the position in the sky where the luminous object seems to disappear. Early reports soon established the approximate limit of observation of the fireball: Sault Ste. Marie to the north, western New York state to the east, Virginia to the south, and Chicago to the west. Since skies were reasonably clear over most of this region, the fireball apparently occurred somewhere in the central part, in the vicinity of Lake Erie (fig. 1).

As end-points were plotted, the lines clearly indicated the fireball passed over Lake Erie from the southwest and disappeared over southwest Ontario (fig. 1). Explosive retorts were heard in the Detroit area three to five minutes after the fireball disappeared. This information indicated the meteorite must have fallen north of Lake Erie in Ontario. The loudest boom marking the end-point of the fireball was produced not more than 35 miles southeast of the heart of Detroit.

Figure 2. Train of December 9, 1965 fireball as photographed by Lowell Wright at Orchard Lake, Michigan. The train consists mostly of debris from disintegration of the meteorite. The remarkable photo below was taken within seconds after the fireball and the one to the right a short time later.

As observations continued to come, two fulfilled our fondest dreams—actual photographs of the train, or smoke trail of the fireball. At Orchard Lake, Michigan, Mr. Lowell Wright was taking sunset pictures. Turning away from the sun toward the southeast, he saw the fireball and quickly snapped two pictures of the train (fig. 2). East of Pontiac, Michigan, Mr. Richard Champine, a professional photographer, was driving southward on I-75. Seeing the fireball, he stopped and took a series of pictures of the cloud produced by the flaming object (fig. 3).

Figure 3. *Another photograph of the train of the December 9, 1965 fireball taken by Richard Champine east of Pontiac, Michigan. This and Wright's photos (fig. 2) were used in computing trajectory (fig. 4) and orbit (fig. 5) of the meteorite.*



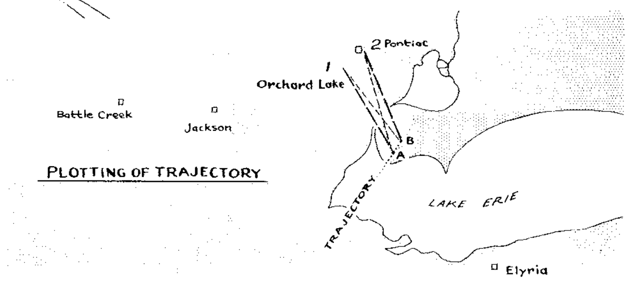


Figure 4. Trajectory of December 9, 1965 fireball determined by triangulation using photographs of the train. Upper left is the trajectory of flight through the atmosphere. The fireball disappeared 14 miles above ground and any meteorites fell as dark objects from that point. At right the trajectory is projected to the ground. Photographs were taken at locations 1 and 2 and used to determine points A and B on the trajectory.

The author and two associates, David Krause and Ralph Johnson, went to both these locations and made transit readings based upon the photographs. The trajectory and end-point of the fireball were then computed (fig. 4). Interviewing residents near the computed end-point revealed the fireball trail did, in fact, end directly overhead in extreme southwest Ontario, thus confirming its trajectory and likely region of fall. A thorough documentation and search were initiated in cooperation with Canadian scientists. Although meteorite specimens have not been found yet fragments probably did reach the ground and may someday be recovered. The approximate orbit of the meteorite before entry into the earth's atmosphere was also calculated (fig. 5).

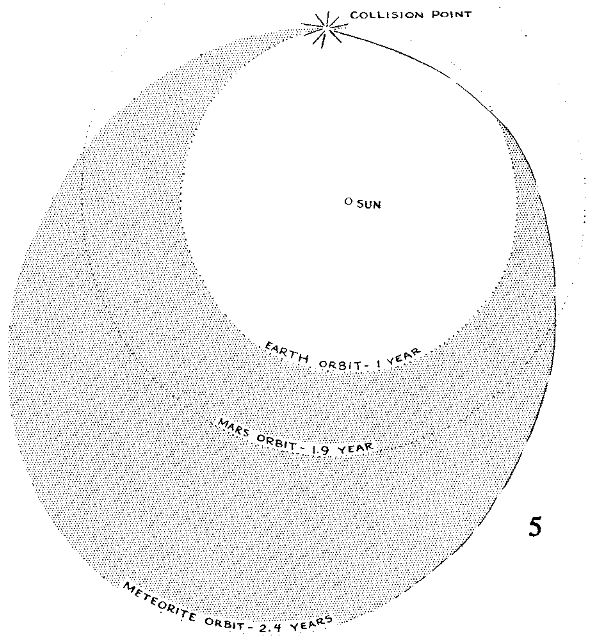
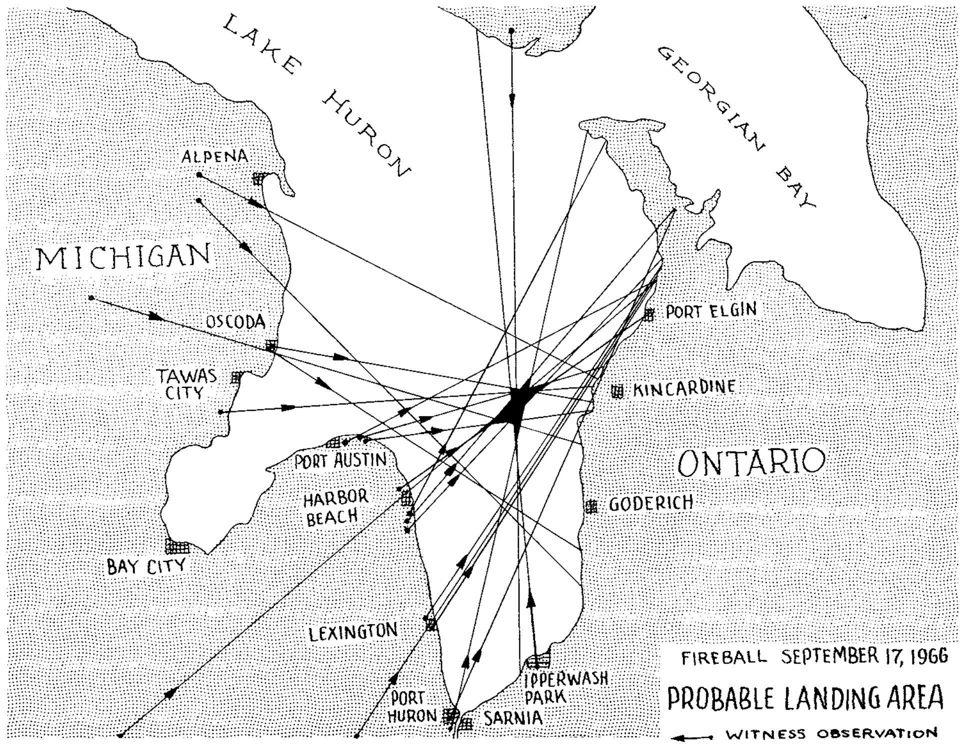


Figure 5. Approximate orbit of the meteorite causing the December 9, 1965 fireball compared to the orbits of Earth and Mars.

Fireball of September 1966. Less than one year later, on September 17, another spectacular fireball was witnessed in the Great Lakes region, this time in a darkened sky. The event occurred on a Saturday evening at 7:47 p.m. E.S.T. This fireball was bright enough to momentarily light the evening sky to a pearly glow almost as light as day. At several communities in the thumb of Michigan the intensity was sufficient to automatically turn off the photoelectric controlled street lights. Typical fireball sights and sounds were witnessed along both the Canadian and United States shores of southern Lake Huron. At least two photographs were taken (frontispiece).

Confused reports of falling objects and fires followed. Because the author was alerted within minutes after the event he was able to locate the train remaining in the sky. With a reliable bearing on the end-point, the region of greatest interest in the United States was quickly determined to be along the Michigan shore of Lake Huron. Some observers in this area were then interviewed. Results indicated a southeast to northwest trajectory ending, unfortunately, over Lake Huron about 50 miles east and slightly north of the tip of the thumb of Michigan (fig. 6).

Figure 6. Observations of September 17, 1966 fireball. Arrows point to the end-point of the fireball as reported by witnesses at several different locations, indicating the fireball ended off shore from Kincardine, Ontario.



The following statements are typical reactions to such an exciting moment.

"Sir: I was sitting around a large outdoor fire at my summer mobile home located on the shore of Lake Huron in Port Hope, Michigan last Saturday evening when the meteorite appeared at 7:46 p.m. It appeared out of the southeast and looked to be traveling in a northwesterly direction. It appeared to be a shooting star and then exploded like a large fire works in a northerly direction. It left a vapor trail due east of Port Hope that was blown inland and passed over Port Hope going in a westerly direction. It was over a minute before we heard the sonic booms and they were numerous—sounded like thunder in distant rain clouds. I thought of taking pictures of the vapor trail but did not think that it would be very clear and of use to anyone.

"I drove to a public phone and called the city desk of the Detroit News and they said that they were receiving numerous calls on the meteor.

"I believe that if there was any part of the meteor left when it reached the earth, that it fell into Lake Huron, north of Port Hope and near Grindstone City, but several miles off shore."

(Joseph L. Whatley, Allen Park, Michigan, September, 1966)

"Dear Mr. Chamberlain: My wife and I read your appeal for information by eyewitnesses of the event of September 17 and decided our experience was worth recounting.

"At 7:45 p.m. Saturday, September 17, my wife, her mother and I were driving down the nearly deserted, darkened beach at Ipperwash, Ontario (traveling in a southwesterly direction). We were at a point about midway between Ipperwash Provincial Park and Kettle Point when the beach, dark except for my headlights, suddenly appeared as bathed in daylight. We could see not only miles down the beach, but the cottages on the dunes and the ripples of the lake.

"This sudden brightness stunned us into silence, lasting five to 10 seconds, perhaps longer, it seemed. I had not enough presence of mind to halt the car immediately in order that I might look to the heavens for an explanation. Not until the light had vanished did I jump out to see what caused the phenomenon. I saw only a vapor—as I would call it—in the sky. It ran at roughly right angles to the beach, indicating to me that something had crossed the heavens from east to west. I argue this was its route for as I recall the event, the light appeared and departed in such a way as to indicate such was the trajectory of the object causing the light (heading toward the west-northwest).

"In any case, after a moment's consideration I drove back up the beach to a point where I had seen a group around a beach fire. This fire was in front of cottages owned by the Richardsons, a corn-roast as it turned out. There were a dozen or more people.

"I talked to Mrs. Richardson concerning the sudden light and she confirmed what I've said above. She guessed that we had seen the effects of a meteorite which headed out over the lake. At the very moment I began conversing with her, we both heard two distinct explosions, separated by a couple of seconds. She said, "Hear that?" indicated the falling body caused the sound—but I wondered how the explosion could come after such a lapse of time. From the time the glow died out to the time of the explosions may have been anywhere from three to five minutes more likely the latter.

"I hope all this helps in some small way in your search for answers to the fall of the meteorite."

(John H. Matle, Detroit, Michigan, September 23, 1967)

Dear Sir: I read in the Detroit News that you were interested in obtaining a more exact location as to sighting the recent meteorite.

"I am a Captain in the Detroit Fire Department. I am neither religious, superstitious, nor addicted to alcohol. I believe what my wife and I saw that Saturday night was as exactly so as I will relate to you.

"We were standing by the shore of Lake Huron while staying at Smith's Motel which is near the Tawas River at Tawas City, Michigan. There were no yard lights on, only a fire burning in a rubbish barrel, next to which we were standing for warmth. There are some willow trees growing near the lake. We were nearly beneath the trees, but not quite. Suddenly a quivering blue light, like a neon tube going on, permeated the area. Then, through the branches of the one willow tree, we saw a huge flare, enlarging, falling—I thought perhaps toward us. We moved about ten feet away from the barrel, to see if the flaring object might be coming our way. At that moment, a meteor-like flare, but somewhat wider moved up the lake, dipping slightly, ending in a bluish light without dropping very low into the horizon. It seemed to end opposite Tawas Point, but apparently far away from land. There was no noise to be heard. I guessed it to be either a meteor or a falling aircraft from the Oscoda Base, some twenty miles north.

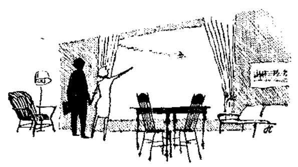
"I would be able positively to place the sighting against the branch of the tree through which I saw the flare and the rubbish barrel next to which I stood."

(Eldon Dreher, Detroit, Michigan, September 23, 1967)

"Dear Sir: I am writing in response to your request for information from residents in the Thumb area concerning the alleged meteor. We live five miles east, one half mile north of Bad Axe, and approximately thirteen miles from the lake at Harbor Beach. The distance is slightly more to Port Austin. My husband and I are in our late thirties, our daughter is seventeen, and we all have good eyesight and hearing.

"We saw the flash, more correctly, it was as if someone turned on a hugh fluorescent light, lighting all the outside with more of a blue-white light than natural daylight. My husband had a better view as he sat facing the open door. He ran outside, my daughter and I right behind him. The light was gone as quickly as it came. We did not see the actual object in the air. The owner of a store at Verona (about a mile east of here) happened to be outside and saw it. He said it was traveling in a northeasterly direction. We would put the time from sixty to ninety seconds after the brightness when we heard the first 'explosion.' Our first thought was of a nuclear device, either intentionally or otherwise exploding in the lake. The noise was unlike anything we had heard before. It was not a steady rumble or roar, and it was not one distinct crash. It was not like thunder. It could be compared to systematic cannon fire, or distant drum beats on very large drums. It was very audible and very grotesque, and there were definite pauses between noises.

"We theorized later it was caused by either a large chunk of the meteorite exploding as it made contact with the water, or several smaller ones, but the latter is rather unlikely since there was only a single object reported in this area at that time. It seemed more in the direction of Port Austin than in Harbor Beach, if the sounds carried in a true direction. I cannot truthfully say whether the sounds lasted one or two minutes, but it was not just one or two, but many times repeated so that there can be no mistake that the object made contact with something close in this area.



"It is our firm conviction that Lake Huron has another secret."

(Mrs. John E. Guza, Bad Axe, Michigan, September 22, 1967)

Other Fireballs. Over the centuries many fireballs have been observed in Michigan. Two recent ones are described above. Most of the recorded accounts have appeared only in newspapers, but a few have been described in scientific literature. For example, geologist W. H. Hobbs analyzed the fireball over western Michigan and northern Indiana on Thanksgiving Eve, November 26, 1919. His account is published in Michigan Academy of Science Papers, 1921, Vol. 1, pages 253-268, 1923.

Painting by John D. Babcock

A Fiery Journey A meteorite entering the earth's atmosphere produces dramatic effects observable over thousands of square miles. Not only is a fiery object seen in the sky, but explosive, rumbling and cracking sounds occur near the actual trajectory. To understand what happens, let us travel with an imaginary meteorite on its collision course with the earth.

The spectacular part of the trip is preceded by a long and relatively uneventful orbit around the sun. Evidence suggests, over the past few billion years meteorites have been produced in space by collisions between asteroids. For a million or so years, our special meteorite has been traveling undisturbed. But now, it crosses the earth's orbit when the earth is also cruising there and its ultimate destiny is imminent—a very small world (the meteorite) and a large one (the earth) will meet in space. If the earth were like the moon, having no atmosphere, the explosive impact of the meteorite on the hard surface of the earth would form a crater much larger than the meteorite itself. However, the earth's blanket of air slows the traveler from space with drastic results.

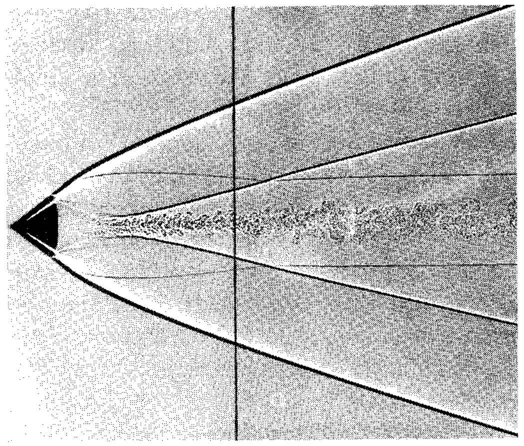
Shock waves begin several hundred miles above the earth's surface. About eighty miles up, there is just enough air to begin the exciting visible effects. The meteorite is moving many miles each second. At such high velocities, even thin air becomes a formidable barrier. As the meteorite begins to strike enough air molecules, some of its energy of motion is changed to heat and light. The surface of the meteorite becomes incandescent and begins to ablate or vaporize. Its interior is not affected because ablation carries the heat away. The air around the meteorite also glows as the result of atomic and molecular excitation, like the glow of a neon tube.

As the denser air of the lower atmosphere is penetrated, the brightness of the glowing meteorite increases and it truly becomes a fireball with a surface temperature of several thousand degrees Fahrenheit. The surface vaporizes and successively new surfaces are formed and destroyed. A shock wave is generated, which upon reaching the ground is heard as a sonic boom. The meteorite moves so rapidly that all the air molecules cannot be forced out of its path, and a mass of air accumulates in front, creating pressure which eventually becomes so great that the meteorite usually bursts into fragments. Bursting may occur several times during the few seconds of glowing flight. Each fragment, still moving considerably faster than sound, produces shock waves creating sonic booms. The turbulent zone behind the meteorite is comparable to that of a supersonic projectile (fig. 7).

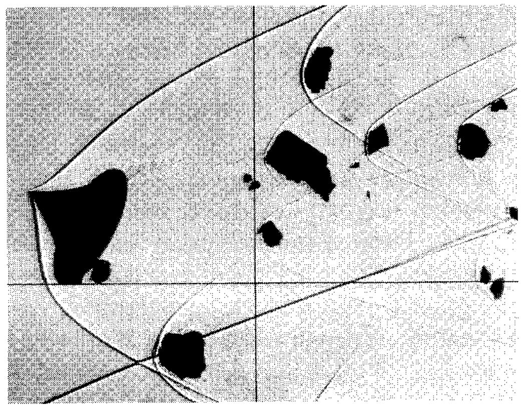
As the meteorite angles through the lower stratosphere its energy of motion is completely dissipated through light, heat, and fragmentation. Its visible flight often ends in one final burst of "sparks" and the fragments drop almost vertically downward the last few miles to the earth's surface.

An observer beneath the trajectory usually first sees the fireball when it is about 80 miles up. It brightens quickly and its path is showered with bursts of sparks followed by a train of powdered debris resembling smoke. The train is best seen

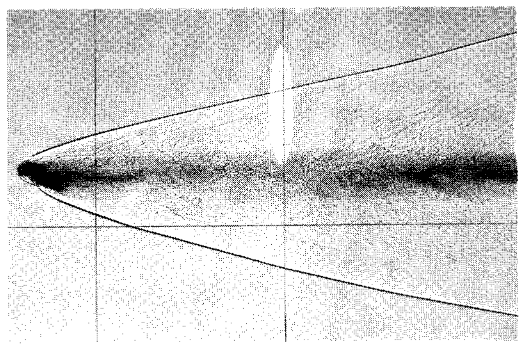
Figure 7. Complex shock waves are generated by a meteorite plummeting through the earth's atmosphere. These are similar to the shock waves produced by very high speed projectiles in ballistic experiments. The accompanying illustrations of hypervelocity projectiles give some insight to the origin of the complex sounds produced by meteorite falls. Reproduced through the courtesy of Ames Research Center, National Aeronautics and Space Administration.



← *Aluminum cone traveling almost four times the speed of sound. The double set of diverging heavy lines are shock wave fronts. The billowy area trailing along the flight path is the turbulent wake. The vertical dark line is part of the recording procedure. A meteorite that does not tumble as it enters the atmosphere develops a rough cone shape through the process of ablation, and generates primary shock waves like these, which upon reaching the ground are heard as loud "booms." Subsequent rumbling sounds produced by the turbulent zone may linger after the main booms have subsided (Enlargement on page 36).*



→ *Cusped projectile traveling at more than four times the speed of sound. A plastic device attached to the projectile fragmented when fired, causing the projectile to oscillate. Note the prominent wave fronts created by each fragment. Atmospheric pressure causes meteorites to fragment like this, causing multiple sonic booms.*



← *Disintegrating graphite cone traveling more than five times the speed of sound. Note the many tiny shock waves produced by the minute particles. The perpendicular black lines are part of the recording procedure. Meteorites disintegrating in this manner add to the confusion of sounds occurring after the fireball (Enlargement on p. 38).*

late in the day as the rays from the setting sun reflect from the cloud. Thunderous shock waves, traveling at the speed of sound, arrive more than a minute after the fireball has disappeared. These reverberations may continue for several seconds when numerous shocks were produced along the trajectory. A rumbling and clattering underlying the main booms may persist for the better part of a minute after the booms themselves have ended. These secondary sounds are caused by supersonic meteorite fragments and turbulance in the wake of the meteorite (fig. 7). In the meteorite fall area an observer may also hear fragments whistling, buzzing or roaring through the air after the booming sounds have subsided. The final event would be the "thuds" of the fragments striking the ground.

Within just a few minutes the meteorite has ended its long journey through space. A glowing flight of a few seconds usually ends about 15 miles above the earth. Much of the meteorite is vaporized or converted into dust. The remaining fragments drop to earth, often not even burying themselves in soft ground.

The preceding description is generally true for meteorites weighing several pounds or more, but considerably less than 100 tons. Very large meteorites in penetrating the earth's blanket of air, maintain cosmic velocities and create "explosion" craters upon impact with the earth's crust. Such events are extremely rare on the time scale of human activities. None have occurred in recorded history. The great crater near Winslow, Arizona was caused by a meteorite probably weighing hundreds of thousands of tons.

In summary, the visible effects of meteorites usually terminate several miles above the ground. When the fireball appears to reach the ground, or almost so, the observer can be sure that he is at least 100 miles from the fall area. This is often difficult to believe. On the other hand, the booming sounds associated with a fireball are heard near the place of fall. If an observer were standing where a meteorite falls, he would still hear the sonic boom before the meteorite struck the ground. Because the meteorite was extremely cold in space and because temperature is dissipated by ablation (vaporization) the meteorite cannot start fires on the ground. Not a single authenticated case of fire started by a meteorite is recorded even though some have fallen in dry straw. Neither has a single case of a meteorite killing a person been confirmed. Ancient records do indicate the possibility, e.g. Old Testament, Joshua 10:11. On November 30, 1954 a woman was struck a glancing blow by a meteorite and slightly injured. For additional material on the subject see Heide, p. 60-61.

II

KINDS OF METEORITES

The three main types of meteorites are: (1) irons, or siderites, composed almost entirely of metal, (2) stones, or aerolites, composed mostly of silicate minerals, and (3) stony-irons, or siderolites, composed of both metallic and stony materials.

Among the meteorite falls which have been observed and recovered, about 92% are stones, 6% irons, and 2% stony-irons. Among meteorites which have been found but not observed to fall, 35% are stones, 59% irons, and 6% stony-irons. This difference is due to the fact that stony meteorites resemble some common terrestrial stones, especially after weathering a few years. Several rare varieties even have a clay-like texture that breaks down within a few weeks.

A simplified classification and description of the principal kinds of meteorites follows.

IRONS (*siderites*)—composed chiefly of iron-nickel alloys kamacite and taenite. May also contain plesite, troilite, schreibersite and graphite (figs. 10, 12, 13, 14, 15, 17).

Octohedrites—6-16% nickel. Polished and etched specimens show Widmanstatten figures. Divided into fine, medium and coarse.

Fine:	kamacite bands 0.05 - 0.5 mm wide.
Medium:	kamacite bands 0.5 - 2.0 mm wide.
Coarse:	kamacite bands wider than 2.0 mm.

Hexahedrites and nickel poor ataxites—contain less than 6% nickel and consist of kamacite only.

Nickel-rich ataxites—contain more than 9% nickel and consist of pure taenite or an irregular mixture of kamacite and taenite.

STONES (*aerolites*)—composed mostly of ferromagnesian (iron and magnesium) silicate minerals, usually with some metal in the form of grains (figs. 8, 11, 16).

Chondrites—contain generally rounded masses called chondrules embedded in a ground mass. Also 5-25% nickel-iron and often up to 5% troilite.

Achondrites—do not contain chondrules and are poor in metal.

STONY-IRONS (*siderolites*)—contain approximately equal amounts of stony and metal materials (fig. 9).

Palasites—oliving stony-irons.

Mesosiderites—pyrexene-plagioclase stony-irons.

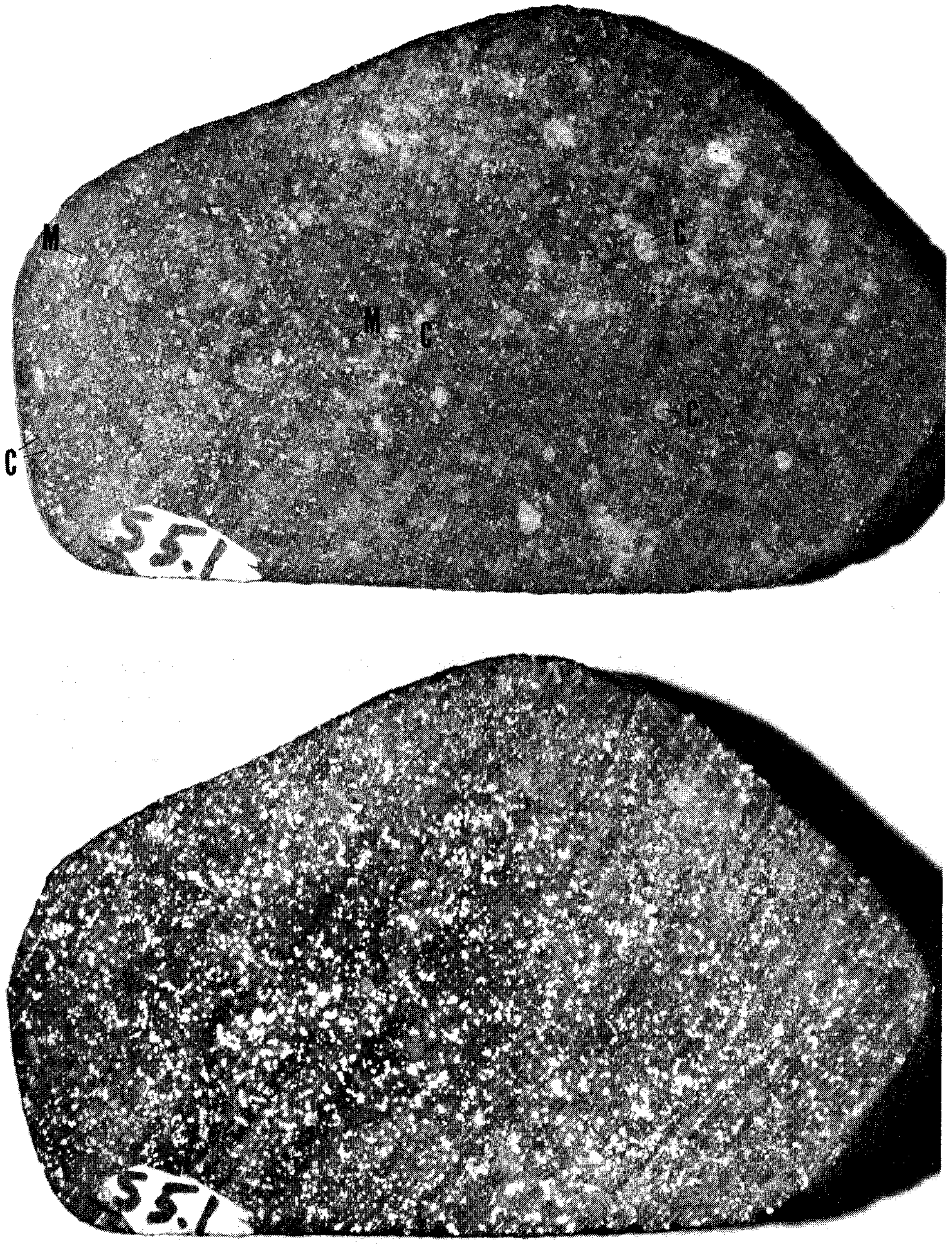


Figure 8. Cut surface of a stony meteorite found near Plainview, Texas. Note the rounded chondrules (C) and the metallic grains (M). Below the same surface is lighted to reveal the polished metal grains which appear white.

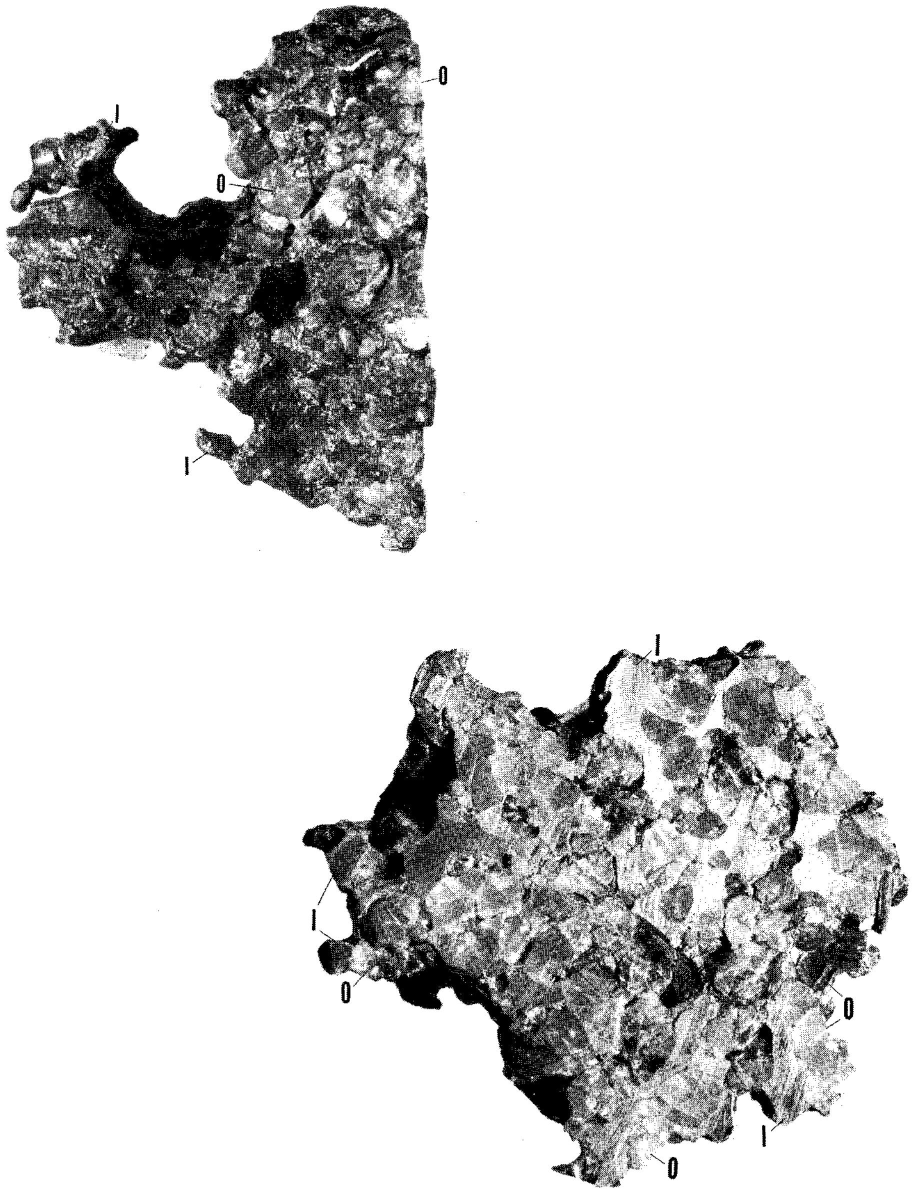


Figure 9. Part of a stony-iron meteorite from Theil Mountains, Antarctica. Upper view indicates weathering of the meteorite. Notice the well developed olivine crystals (O) which are imbedded in the meteortic iron (I). The cut surface in lower photo shows that the olivine (O) occurs as generally rounded crystals surrounded by the iron (I).

III

HOW TO IDENTIFY SPECIMENS

The physical appearance of meteorites varies considerably. Furthermore, they often resemble some terrestrial rocks and man-made slags. Identifying meteorites, therefore, can be rather difficult. Familiarity with numerous examples in museums or other collections is essential. Meteorite recovery, on the other hand, depends largely upon the curiosity of those not students of the subject. Most meteorites are found by people who work the soil. Recognition of specific characteristics especially those acquired during flight, will help determine whether a suspected meteorite should be submitted to a specialist for further study.

Fusion Crust. An unbroken stony meteorite will be encased in a fusion crust composed of silicate minerals fused into a natural glass (fig. 11) often veined with fine flow lines. Fresh fusion crusts are usually black. Lighter colored varieties are known, sometimes even white, but are rare. In any case, as the crust weathers it will usually turn dark brown.

Newly fallen iron meteorites have a black fusion crust of oxidized iron. Irons are likely to contain regmaglypts or pits resembling thumbprints (fig. 14). When weathered the surface becomes rusty. A very old iron will likely have no fusion crust, the surface having flaked away by weathering.

Specific Gravity. Iron meteorites are heavy, having a specific gravity of about 7.7. Stony irons range from about 4.5 to 6.0. Most stony meteorites range from 3.0 to 4.0. Thus meteorites are generally heavier than most field stones which have specific gravities of about 2.7. Stony meteorites, however, are not easily recognized on this basis.

Magnetism. The first and simplest test is magnetism. Iron meteorites are strongly magnetic. But so are terrestrial minerals such as magnetite, pyrrhotite or maghemite (see mineral list in mineralogy section) as well as man-made slag. Most meteorites, including stony meteorites contain sufficient magnetic metal to make them at least slightly magnetic, but this test is not conclusive because some stones are non-magnetic.

Examining Interior. Suspected meteorites should be treated with care. They should not be broken to examine their interior. A very small area of the surface of the suspected meteorite may be ground off for examination. Care should be taken to use a grinding agent harder than the object studied. For example, traces of a file could be imbedded on the prepared surface of a harder specimen and mistaken for metal grains. When the fresh interior is exposed it should be examined for metallic inclusions. If the prepared area is entirely metallic, the object may be an iron meteorite or a metallic portion of a stony-iron. The metallic grains in most stony meteorites will show up as brilliant smears or reflections. If the

specimen is an iron meteorite, it will probably be an octahedrite. Such a specimen can be polished and etched with an appropriate acid to reveal Widmanstatten figures (figs. 12, 14, 15). A specimen possessing such structure is surely a meteorite.

Test for Nickel. If metal is present, the next step is to test for nickel. This may be the time to have the specimen examined by one thoroughly familiar with meteorites. Though the test for nickel is not difficult, it should be made only by a person thoroughly familiar with chemicals. A small sample should be ground to powder and dissolved by heating in dilute nitric acid. Upon cooling, ammonium hydroxide should be added, converting the solution from an acid to a base. If iron is present a brown residue will appear which must be removed by filtering. A few drops of dimethyl-glyoxine alcohol should be added to the remaining clear solution. If nickel is present, a distinct pink color will appear.

The presence of nickel-iron suggests that a specimen is a meteorite, though this is not absolutely conclusive. Certainly the specimen should be examined by a qualified specialist.

Chondrules. Chondrules are an identifying characteristic of most stony meteorites. These appear on a flattened surface as round masses varying in size from about one millimeter to several millimeters (fig. 8).

Summary

Meteorites not severely broken or weathered have a fusion crust. Most meteorites are magnetic due to inclusions of nickel-iron. Magnetic specimens will test positive for nickel. Most stony meteorites contain chondrules.

IV

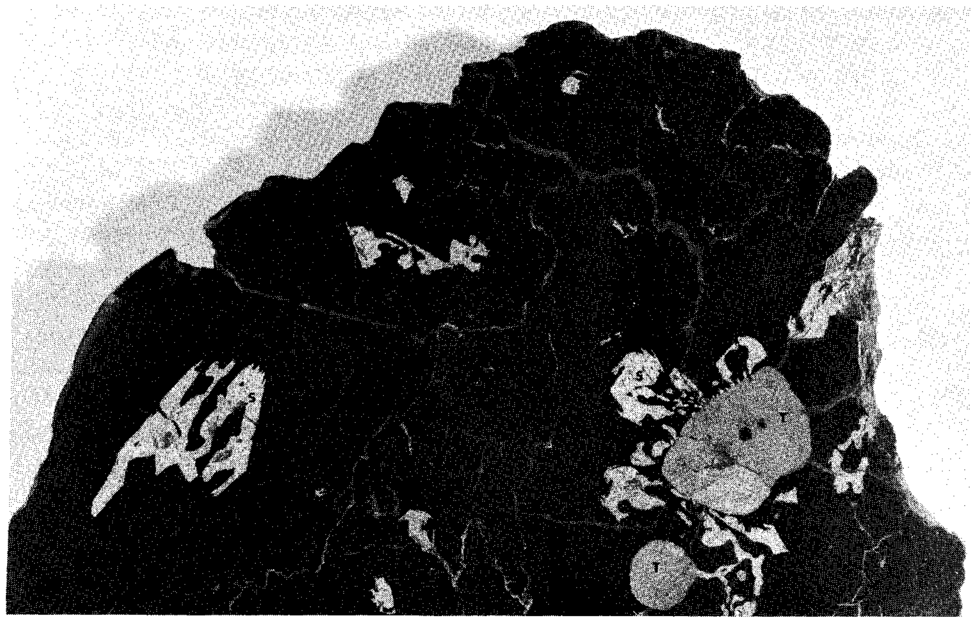
MINERALOGY

Minerals consist of naturally occurring chemical elements or combination of elements. Some form under conditions of low pressure and low temperatures, while others require high pressure and temperature. Some form into crystals rapidly, others more slowly. Some require water, others do not. Knowing how they form helps determine the history of natural materials.

The presence or absence of specific minerals in specimens are clues to their geologic history. When samples from the moon's surface become available mineral structures will be of great interest. In the future we expect to know more about the physical history of some of the other planets by studying their minerals. So far meteorites provide the only mineral samples from beyond our earth, and their composition is of great interest in determining their origin and relationship to the rest of the solar system.

Meteorites contain many minerals which are also found in the earth's surface. In addition they contain minerals differing slightly from those found on earth, having been formed in the absence of water and air. The subject of meteoritic minerals is complex. Only a sketch of the topic is presented here. A list of minerals found in meteorites appears at the end of this section.

Figure 10. Section of the Central Missouri iron meteorite. "S" mark inclusions of Schreibersite: "T", troilite. Specimen about actual size.



Irons

Native iron rarely occurs on earth because iron readily combines with oxygen and other elements. Indeed, iron meteorites begin to oxidize upon entering the earth's atmosphere. They reach the ground covered by a fusion crust of magnetite. Once on land, they, like other iron objects, oxidize in the presence of moisture. Before oxidation, the iron in meteorites occurs in a solid solution with nickel. This compound is usually present as a minor constituent of stony meteorites, but comprises almost the entire content of irons.

Nickel-iron occurs in two distinct minerals. *Kamacite,* the alpha iron of metallurgists, contains from 5.0 to 6.8% nickel, and crystallizes as a body-centered cubic lattice. *Taenite*, or gamma iron, has a much more variable and greater content of nickel, ranging from 27 to 65%, and crystallizes in a face-centered crystal lattice. It is more resistant to acid than Kamacite.

The origin of their names is interesting. Kamacite comes from the Greek "kamas" meaning bar or girder. Taenite is from the Greek "taenia" meaning a band or strip. The most common type of iron meteorites, the octahedrites, consist of an interesting combination of these two minerals. The kamacite is in the form of bars and the taenite is mostly found as strips bounding the kamacite bars. The classification of octahedrites into fine, medium and coarse is based on the width of the kamacite bars. This crystalline structure is revealed when a polished surface is etched with acid. The more resistant taenite retains its polish while the kamacite is attacked and dulled by the acid. The result is the unique *Widmanstatten figures* (figs. 12, 14, 15). The size of the kamacite bars is due to nickel abundance and rate of cooling. Interspersed as fields in the kamacite bars and taenite strips is a third form of nickel-iron called plessite which is actually a mixture of kamacite and taenite.

Hexadrites and *nickel-poor ataxites* consist of kamacite except for inclusions of sulfides and other minor components. Nickel-rich ataxites consist almost entirely of taenite.

Other important minerals occurring in iron meteorites are troilite, graphite and schreibersite (fig. 10). *Troilite* was named for the Italian, Troili, who discovered this mineral in a meteorite in 1766. It is iron-sulfide and differs from the terrestrial variety in having a more nearly equal amount of iron and sulfur, and a great specific gravity. It often contains small quantities of chromium, nickel and sometimes copper. Troilite occurs in iron meteorites as rounded nodules or thin plates often surrounded by schreibersite and sometimes with daubreelite intergrowths. *Graphite* commonly occurs in iron meteorites as grains, nodules or plates. *Schreibersite* occurs only in meteorites. It is an iron-nickel-cobalt-phosphide, $(Fe, Ni, Co)_3P$, difficult to dissolve in acids and, therefore, brilliant on the etched surface of an iron meteorite. It occurs in a hieroglyphic form, in plates or as "rhabdite"—minute needle-like crystals occurring frequently in hexahedrites and ataxites. Iron meteorites contain other minerals in small amounts.

Stones

The major mineral components of stony meteorites are *olivine* (Mg, Fe)$_2$ SiO$_4$, and *pyroxene* (Mg, Fe)SiO$_3$. Olivine is the most abundant silicate in meteorites. Usually occurring as the magnesium-rich variety, it is present in some achondrites as well as chondrites. The pyroxenes, occurring as *enstatite, bronzite* and *hypersthene,* generally occur with olivine and provide a system for classifying stony meteorites. The pyroxenes determine the color of most stones. In addition to the above *plagioclase* is common in the light-colored chondrites. The minerals mentioned in the preceding section on iron meteorites are also common as grains in stones. Still other minerals are present in stony meteorites in minor amounts.

Stony-Irons

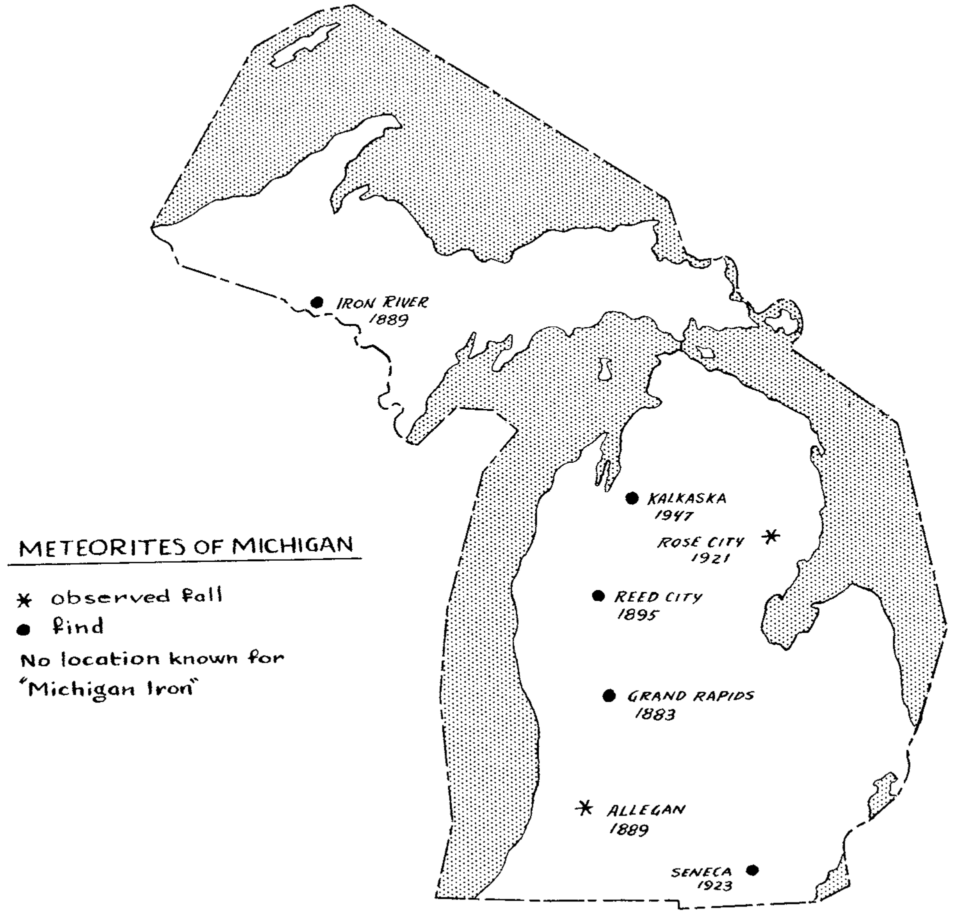
Both silicate and iron phases are present in this group of meteorites. *Pallasites* (fig. 9) consist generally of large rounded, angular or brecciated olivine crystals filling the cavities of a nickel-iron network. *Mesosiderites* contain approximately equal amounts of silicates and nickel-iron, the latter occurring as grains of varying sizes distributed throughout the pyroxene and plagioclase.

Mineral List

Below are listed the mineral terms referred to in the preceding and other sections of this book. Further information about most of them is available in books on mineralogy.

Albite:	Silicate mineral of the plagioclase series with the formula $NaAl_2Si_3O_8$.
Anorthite:	Silicate mineral of the plagioclase series with the formula $CaAl_2Si_2O_8$.
Bronzite:	Pyroxene with 10-20% $FeSiO_3$.
Daubreelite:	Mineral found in iron meteorites. Usually associated with troilite. Soluble in nitric acid but not in hydrochloric acid. Chemical formula $FeCr_2S_4$.
Enstatite:	Pyroxene wth less than 10% $FeSiO_3$.
Graphite:	A mineral form of the element carbon.
Hypersthene:	Silicate mineral of the pyroxene group with the formula (Mg, Fe)SiO_3.
Limonite:	Hydrous iron oxide having variable composition.
Maghemite:	Magnetic variation of the mineral magnetite.
Magnetite:	An oxide of iron, Fe_3O_4.
Olivine:	The most abundant silicate in meteorites. Its formula is (Mg, Fe)$_2SiO_4$.
Plagioclase:	Group of silicate minerals ranging in composition from pure albite to pure anorthite.

Plessite:	Nickel-iron mixture of kamacite and taenite.
Pyroxene:	General name given to a large group of feromagnesian silicate minerals with the general formula (Mg, Fe)SiO_3.
Rhabdite:	Thin plates of schreibersite appearing as needles on an etched surface of an iron meteorite.
Schreibersite:	Hard, metallic white, nickel-iron mineral found only in meteorites. Difficult to dissolve in acids and therefore, brilliant on the etched surface of an iron meteorite. Resembles taenite in appearance. Its chemical formula is (Fe, Ni, Co)$_3$P.
Taenite:	A metal found in most meteorites consisting of iron with 27 to 65% nickel. More acid resistant than kamacite, and therefore, more brilliant upon the etched surface of an iron meteorite. Often occurs as thin bands bordering kamacite bands in octahedrites.
Troilite:	Bronze-yellow mineral (FeS) found in meteorites. Occurs as rounded nodules or thin plates in iron meteorites and as grains in stony meteorites.



V

DOCUMENTED FINDS AND FALLS IN MICHIGAN

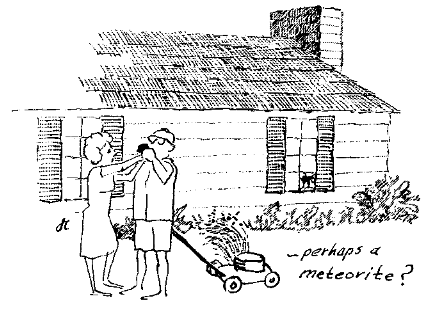
Eight meteorites have been positively identified in Michigan. Numerous other objects have been claimed to be meteorites, but those examined by the author proved to be terrestrial stones and man-made slag. Several have gained considerable attention.

One of the obvious "meteor-wrongs" of Michigan is located in the Upper Peninsula at a service station three-and-one-half miles east of Shingleton on highway 28. In 1912 woodsmen in the area saw a fireball, noting its apparent course toward the horizon. Later a metallic object was located and removed and has ever since been said to be the meteorite. It is, however, a large, flattened piece of slag. The evidence strongly suggests that the fireball observed by the woodsmen faded out near the horizon at a considerable distance from the region. This event was probably another case where a spectacular fireball convinced viewers it landed nearby. Although the remembrance of such an event generally soon fades, this one is recorded upon Michigan geography. The local railroad spur received the name Star Siding. The nearby creek still bears the name Star Creek.

Another instance of incorrect labeling is located near Grand Marais, Michigan. This error probably originated like many other similar examples known to the author. Perhaps a local resident spotted an unusual object, in this instance a huge glacial boulder, some time after he had witnessed a spectacular fireball appearing to fall in the same direction, and incorrectly linked the two events. Experiences like this serve to emphasize the need for much care in reporting and interpreting dramatic but unfamiliar events.

Doubtless, other real meteorites are present in Michigan. The author and others are extremely interested in locating true meteorites because of their great scientific importance. Anyone aiding in the discovery, identification and availability of a meteorite contributes significantly to science.

The eight confirmed finds in Michigan are the Allegan, Grand Rapids, Iron River, Kalkaska, Michigan Iron, Reed City, Rose City and Seneca Township meteorites. Allegan and Rose City were observed meteorite falls. Some evidence indicates that the Seneca Township meteorite was also an observed fall. The Allegan and Rose City meteorites are stony whereas the others are iron.



Allegan

On July 10, 1889 just after 8:00 a.m. a meteorite fell within the village limits of Allegan, Michigan. The fall was accompanied by thunderous and rumbling sounds. Witnesses saw it bury itself about one and one-half feet deep in the sand and, within a few minutes, dug it out. The original weight has been estimated at 70 pounds. Although evidence indicates other fragments may have fallen, no other recoveries have been reported.

Pieces of the meteorite were broken off by those who found it. The main mass, weighing 62½ pounds, and a smaller fragment weighing 1¼ pounds, became the property of the United States National Museum. Other pieces were acquired by Wards Natural History Establishment. Presently a small specimen is now in the Perry collection at the University of Michigan and another is at Michigan State University. The United States National Museum still possesses most of the original specimen but pieces are at the British Museum of Natural History, and perhaps elsewhere.

Allegan is a stony meteorite of the chondritic variety. The diameter of the chrondrules varies from mostly one or two millimeters to nearly five millimeters (1 millimeter is about 1/25 inch). They also vary in shape from spherical to elongated and irregular. The pitted surfaces on some indicate they had been pressed together. The olivine and enstatite chondrules, together with dark gray silicate materials, are imbedded in a light gray groundmass. The groundmass is composed of grains of olivine and enstatite as well as metallic grains of nickel-iron, iron sulphide and chromic iron. The entire mass is very fragile and except for the broken surfaces were covered by a fusion crust varying in thickness from about one to three millimeters (fig. 11).

The following excerpt from a October 9, 1965 letter received from Mrs. A. Fitch of Grand Rapids, Michigan, illustrates how memorable a meteorite fall can be.

> "Since all this space work became top news, and all this special interest in meteorites, I have thought many times of hearing the meteor which fell in 1899 and landed north of Allegan Village, in Allegan County.
>
> "Our farm was 18 miles north of Allegan Village, in Ottawa County. I was 11 years old. My brother and sisters and I were weeding the potato field, which was just south of our 30-acre woods.
>
> "When we first heard it, we thought it was in the woods—it made such a crashing noise—but we soon realized it was up in the sky. It made banging, swishing, pounding, hissing sounds. It came from the north, and when the noise stopped, it was very quiet. The next day we heard it had landed north of Allegan. Hearsay was that it went 20 feet into the earth and was too hot to get near till the next day. Later I saw a chip of this meteor, a flint-like stone, the size of a 2-inch arrowhead."

Further information on the Allegan meteorite is reported in the following references: (1) H. L. Ward, American Journal of Science, 4th series, Vol. 8, No. 48, December 1899. (2) G. P. Merrill, and H. N. Stokes, Proceedings Washington Academy of Science, Vol. 2, p. 41-68, July 25, 1900. (3) A. S. King, Popular Astronomy, Northfield, Minnesota, 1936, Vol. 44, p. 282.

Figure 11. Three views of the Allegan meteorite. Note cracked fusion crust. Longest dimension about 12 inches (from Washington Academy of Science Proceedings, July, 1900).

Grand Rapids

The first scientifically authenticated meteorite from the state of Michigan was found in May 1883 by Michael Clancy, a contractor who uncovered the meteorite about three feet below the surface. Mr. Clancy kept his discovery secret for weeks attempting to cut it with hammer and chisel, thus damaging a beautiful specimen.

The meteorite was acquired by Mr. C. G. Pulcher, who displayed it in his store window where it was seen by I. R. Eastman. Eastman had a few grains analyzed by scientists of the Smithsonian Institution and they later examined the entire meteorite in more detail. It weighed 114 pounds and was roughly pear-shaped being about 14 inches long and 9½ inches in the greatest diameter.

Pieces of this meteorite are now at the United States National Museum, Chicago Natural History Museum, American Museum of Natural History, Harvard University Mineral Museum, Nininger Collection at Arizona State University, Yale University, University of Brazil, Vatican Collection, Michigan State University and Grand Rapids Public Museum.

Grand Rapids is a fine octahedrite. The etched surface shows beautiful Widmanstatten figures (fig. 12). Its chemical composition is 88.71% iron, 10.69% nickel, and traces of other elements.

Further information on the Grand Rapids' meteorite is reported in the following references: (1) I. R. Eastman, American Journal of Science, 3rd series, Vol. 28, p. 299-300. (2) R. B. Riggs, American Journal of Science, 3rd series, Vol. 30, 1885; and Bulletin, U. S. Geological Survey, Vol. 7, p. 94, 1887.

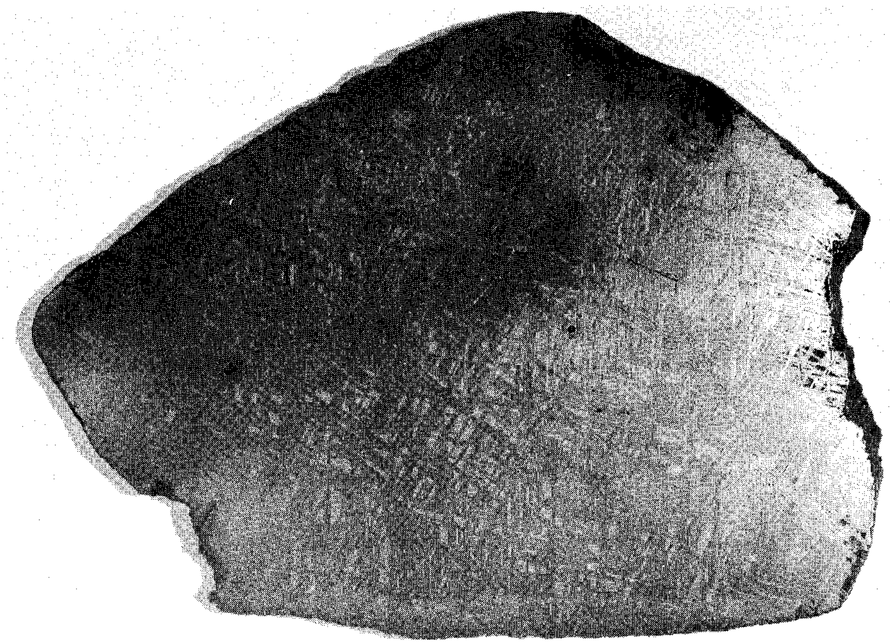


Figure 12. Etched section of Grand Rapids fine octahedrite. Note Widmanstatten structure. Small, rounded, dark inclusions in interior are troilite. Dimensions are 9 x 6½ inches (Michigan State University collection).

Iron River

This iron meteorite came to the attention of the author on March 4, 1965, in connection with news activity of another meteorite. Michigan newspapers ran an article on the discovery of the Kalkaska meteorite. Reading the article, Mr. Ellsworth M. Peterson of Lansing remembered that his father, Peter C. Peterson, had an object believed to be a meteorite. The younger Peterson acquired the meteorite and donated it to the collection at Michigan State University.

The elder Peterson found the meteorite in 1889, at the age of 6, while helping his father clear land near Iron River. Although he thought it was unusual, his father told him it was like the other stones abounding in the region. The boy kept it, however. Later it was taken to a mining company and supposedly identified as a meteorite.

The weight of the meteorite as it came to the University was 1420 grams (roughly 3 pounds). It is somewhat kidney-shaped, rather smooth on one side, and rougher on the other (fig. 13). The smoother side contains a few remnants of striated fusion crust. No fusion crust is apparent on the other surfaces. The surface has marks produced by a sharp tool such as a chisel.

This specimen contains 8.1% nickel. Dr. Hans Voshage of the Max Planck Institute (Otto Hahn Institute) has determined the cosmic-ray exposure age of this meteorite to be 360 ± 70 million years indicating it had been in space as a relatively small body this length of time, perhaps originating from some cosmic collision about 360 million years ago.

Figure. 13. Iron River iron meteorite. A remaining bit of fusion crust is marked "F". Note tool mark. Dimensions are about 4½ x 3 inches.

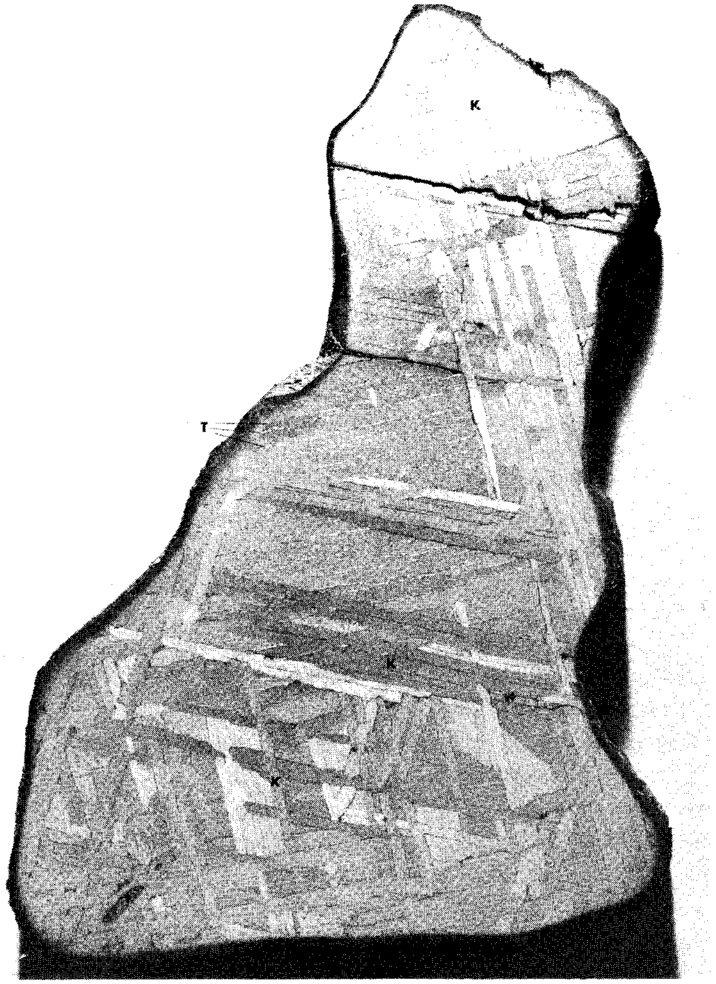


Figure 14. Kalkaska meteorite. (Left) Widmanstatten structure on etched surface. Wide bands marked "K" are Kamacite. Brilliant narrow streaks marked "T" are taenite. Small oval inclusion at bottom left, marked "t" is troilite. Dimensions are about 3½ x 2⅙ inches. (Below) The light depressions, most prominent at left, are regmalgypts. Dimensions are about 8½ x 6 inches. (Michigan State University collection).

Kalkaska

This iron meteorite was discovered by Arthur R. Sieting in 1947 or 1948 while working his field. He heard the cultivator blades strike metal. Upon locating the object it turned out to be heavier than suspected. He therefore took it to his home for several years. Mr. Sieting's brother-in-law, Mr. Kirkpatric, saw the object, and suspecting it was a meteorite, took it to Michigan State University. After identification it was returned to Mr. Sieting, but in 1964 he donated it to the University collection.

Kalkaska is irregularly shaped and shows well-developed regmaglypts resembling thumbprints (fig. 14). Portions of the surface contain fusion crust. It is a medium octahedrite. Cut surfaces contain inclusions of troilite with daubreelite intergrown in them. Polished and etched surfaces reveal beautiful Widmanstatten figures (fig. 14).

Most of the meteorite is at Michigan State University. Pieces also are at the United States National Museum, Arizona State University and Max Planck Institute. A cast of the meteorite, showing its appearance before cutting, is also at Michigan State University.

Further information on the Kalkaska meteorite is reported by the author in "Meteoritics," The Journal of the Meteoritical Society, Vol. 2, No. 4, p. 361-5, June, 1965.

Michigan Iron

The United States National Museum has two meteorite specimens they call the "Michigan Iron." The specimens weigh 48 grams (1.7 oz.) and 62 grams (2.2 oz.) and show an octahedrite structure. The museum obtained them from S. H. Perry who until his death in 1957 was actively engaged in meteorite recovery. Mr. Perry had reportedly obtained these portions of meteorite from the owner who was unwilling to part with the main mass. The location of find of this meteorite is currently unknown as is also the main portion of the meteorite.

The author has subsequently found that another portion of the meteorite, weighing 126 grams is in the Perry Collection at the University of Michigan.

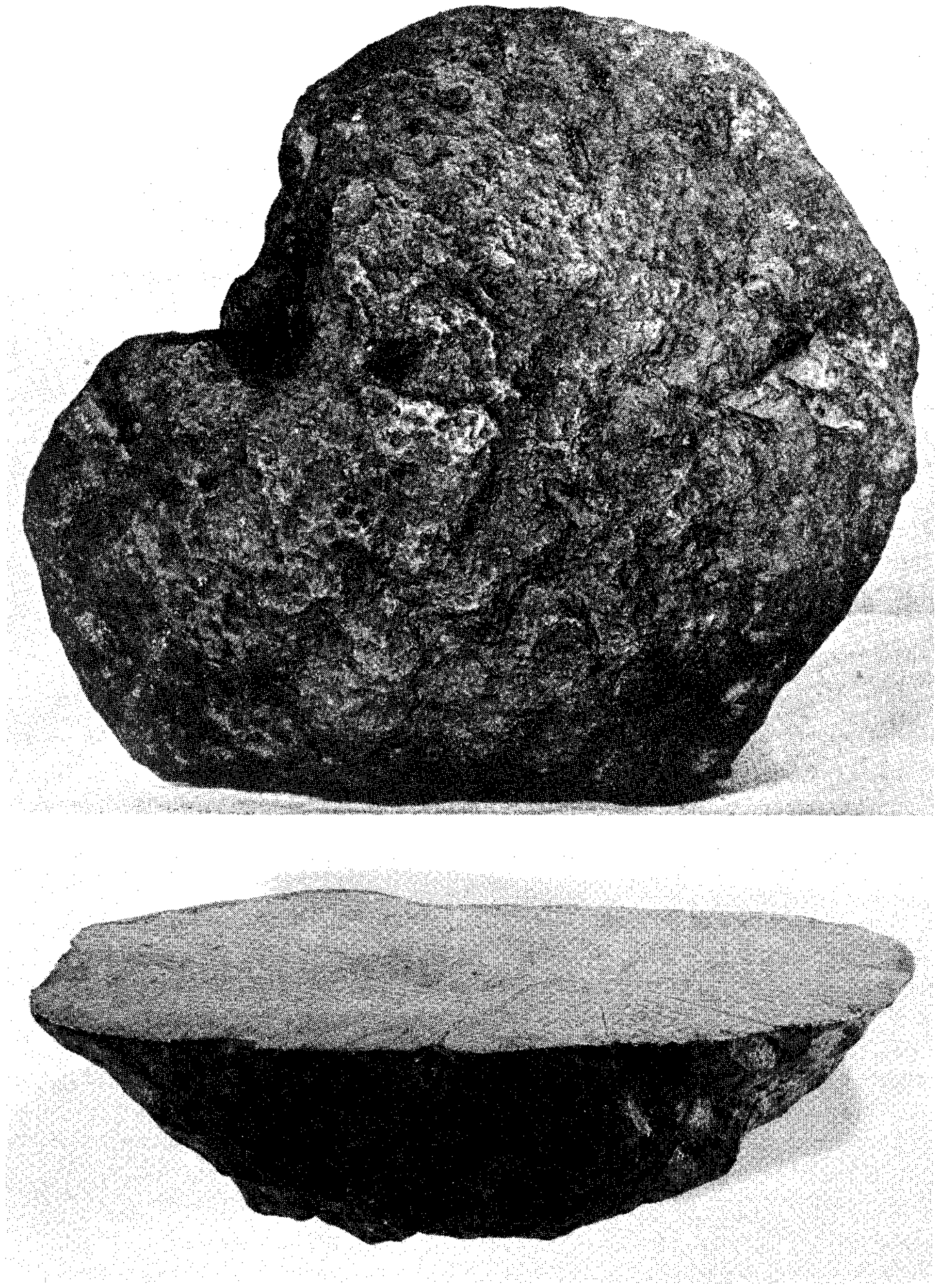


Figure 15. Reed City meteorite. Upper figure is original specimen illustrated in Journal of Geology, 1903. Lower figure is 8½ x 3½ inch section in Michigan State University collection. Note Widmanstatten figures.

Reed City

This iron meteorite was found in September, 1895 by Mr. Ernest Ruppert on his farm near Reed City in Osceola County. While being displayed in a Reed City hotel window at a later time it was recognized by Professor Walter P. Barrows of Michigan Argricultural College (now Michigan State University) which eventually purchased the specimen.

The original specimen was about 4 x 8 x 10 inches in diameter, and somewhat "ham-shaped," and weighed 43 pounds 11 ounces. It is a medium octahedrite containing long needle-like inclusions of schreibersite (fig. 15). It is composed of 89% iron, 8% nickel and small amounts of other elements. Pieces are located at Michigan State University, Chicago Natural History Museum, Yale University, The British Museum, and the Geological Survey of Canada.

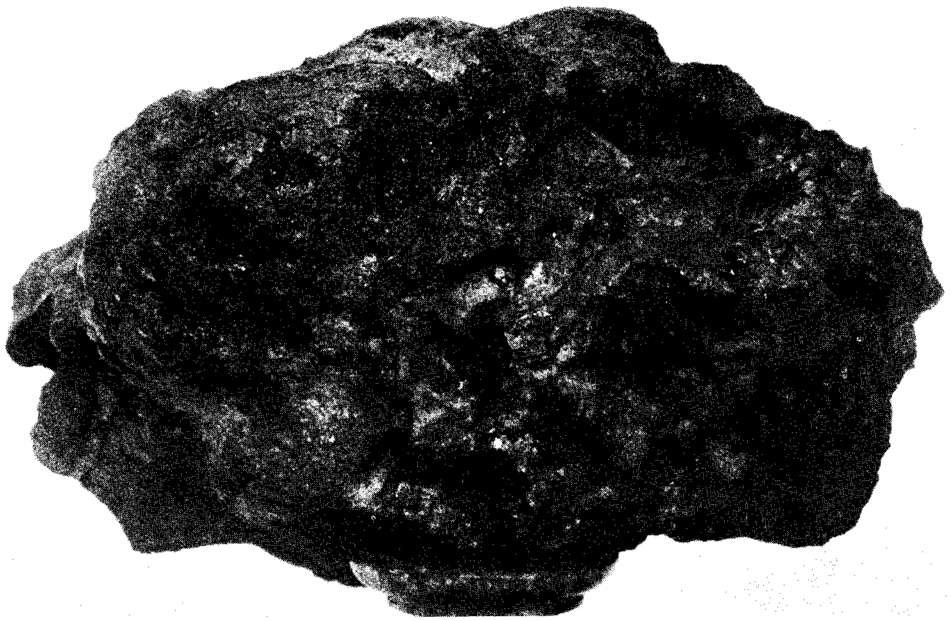
Further information on the Reed City meteorite is reported by H. L. Preston in the Journal of Geology, Vol. 11, p. 230-3, 1903, and in Proceedings of the Rochester Academy of Science, Vol. 4, p. 89-91, April 15, 1903.

Rose City

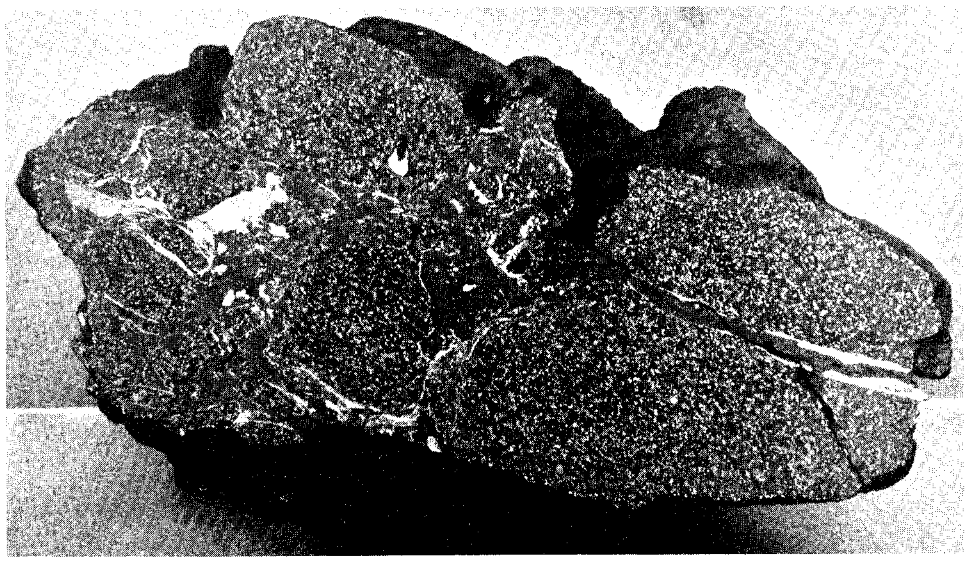
On the evening of October 17, 1921, at about 11:00 p.m. a bright meteor was observed over Michigan's lower peninsula. It exploded, with effects described previously in the vicinity of Rose City. Two fragments were found the next day on George Hall's property near Rose City. One 13-pound piece was found forty feet from the house. Another 7-pound piece was found later 150 feet from the house near a highway.

E. P. Hovey (1922, 23) states that the larger stone was found embedded about two feet deep in soft sod-covered ground while the smaller one was not so deeply buried. H. H. Nininger (1959) on the other hand, states that Mr. Hall claims the larger stone turned up only about 2 inches of sod, while the smaller piece was buried to a depth of 30 inches. A man camping about 14 miles from the Hall farm gave this account of the bolide.

> "I was sleeping in my tent that night and all at once I saw things very light outside. I quickly looked out and saw high in the sky, about five miles I should think, a large ball of fire, and this looked to me as large as an ordinary barn. After the ball had traveled on its way, and the light had died out, I heard three loud explosions, one immediately following the other." (Hovey, 1923)



(a)



(b)

Figure 16. Rose City meteorite. (a) A fragment with dimensions about 8 x 5 inches. (b) Section showing unusual occurrence of metal flow patterns. Also note the scattered metal grains. Dimensions are about 8 x 4 inches (from American Museum Novitates, Nov., 1922).

Mrs. Hall reported:

> "I saw it very light out of doors and heard a roaring sound and then three loud explosions. I thought it was an airship and it was dropping some bombs or something of that character. I jumped up and ran to the door, and the big light was disappearing in the south. The roaring itself was not so very loud, but the explosions were very loud ineed, and while I stood in the doorway watching the disappearing light I distinctly heard a sound like a fine singing." (Hovey, 1923)

Three fragments were reported to have been recovered. Grass and grass roots were imbedded with soil in the pits of one of the pieces when first examined by E. O. Hovey at the American Museum of Natural History. The grass showed no evidence of extensive heat.

The meteorite has been identified as an olivine-bronzite chondrite containing 78.87% silicates, 17.25% metal and 3.88% troilite. The metal phase is composed of 90.5% iron, 8.6% nickel, and small amounts of other elements.

The structure of this meteorite is unusual. The chondrules are deformed and show evidence of heating. The metal has flowed through the stony material as though the entire mass had been heated to a somewhat plastic stage. The color of the interior of the meteorite is black instead of gray (fig. 16b). The surface contains unusually deep holes not thought to have originated during its fiery passage through the atmosphere (fig. 16a). These facts suggest cosmic collision. Another theory is that the meteorite was heated during passage near the sun.

Specimens of Rose City are in the American Museum of National History, United States National Museum, Chicago Natural History Museum, the Nininger Collection at Arizona State University, Harvard University, Perry Collection at the University of Michigan, the British Museum, and Michigan State University.

Further information on the Rose City meteorite is reported in the following references: (1) E. O. Hovey, Journal American Museum of Natural History, Vol. 23, No. 1, p. 86-88, 1923, American Museum Novitates, No. 52, p. 1-7, 1922. (2) H. H. Nininger, Out of the Sky, Dover, 1959, p. 152.

Seneca Township

An iron meteorite was discovered by Louis A. Robin in July 1923 while cultivating corn on the farm of Sidney A. Perry in Lenawee County. Lenticular in shape, it measured about 9½ x 7½ x 3 inches and its original weight was about 25 pounds (fig. 17). It is a fine octahedrite containing numerous inclusions of troilite. Analysis at the United States National Museum indicated 87.77% iron, 11.41% nickel, small amounts of cobalt, copper, sulphur and phosphorus with traces of other elements (Merrill, 1927).

The surface of the meteorite was badly weathered and contained none of the original fusion crust, suggesting it had fallen to earth long before its discovery. In spite of this evidence, Stuart H. Perry believed this specimen resulted from a fireball observed in 1903. Here is his account:

"It was about the hour of sunset and they (Sidney A. Perry and his two brothers) were standing near the farm house which is on a rise of ground and commands a rather wide view to the north and west. It was not yet dark, the air was still, and the western sky was filled with the dark clouds of a distant thunderstorm. Mr. Perry judged that the storm must have been more than 15 miles distant. As they were looking at the sky a brilliant fireball suddenly appeared against the dark background of the clouds.

"The spot where it appeared as fixed by numerous landmarks, was due west from where the observers stood and near the horizon. By sighting along a rod Mr. Perry indicated the spot, which by measurements, was about 10 degrees above the horizon. It seemed at first to be coming directly toward them and they wondered whether it would strike where they stood, but as it approached it seemed to move more and more toward the south until its position was about west-southwest of the observers, at which point it ceased to be luminous and was lost to view. Its course was described as parallel with the horizon and so low that it seemed to skim the tops of the trees, and at one point, even appeared to pass between the observers and a distant tree. It gave a brilliant white light at first, throwing off sparks; then the color changed to red, which became dimmer until it was no longer visible.

"They did not hear any detonating sound that they connected with the meteor. Mr. Perry, however, mentioned that once they heard what they supposed was faint thunder from the distant storm.

"Mr. Perry said the meteor was visible for two or three seconds. A little later (he said a few seconds but could not estimate the time closely) a noise was heard such as he imagined a cannon ball might make—'a rushing sound with a hiss.' The noise ended in a hay field at a point about 150 or 160 yards directly southwest of where the men stood, and at the same instant a sound was heard like that of something striking the earth.

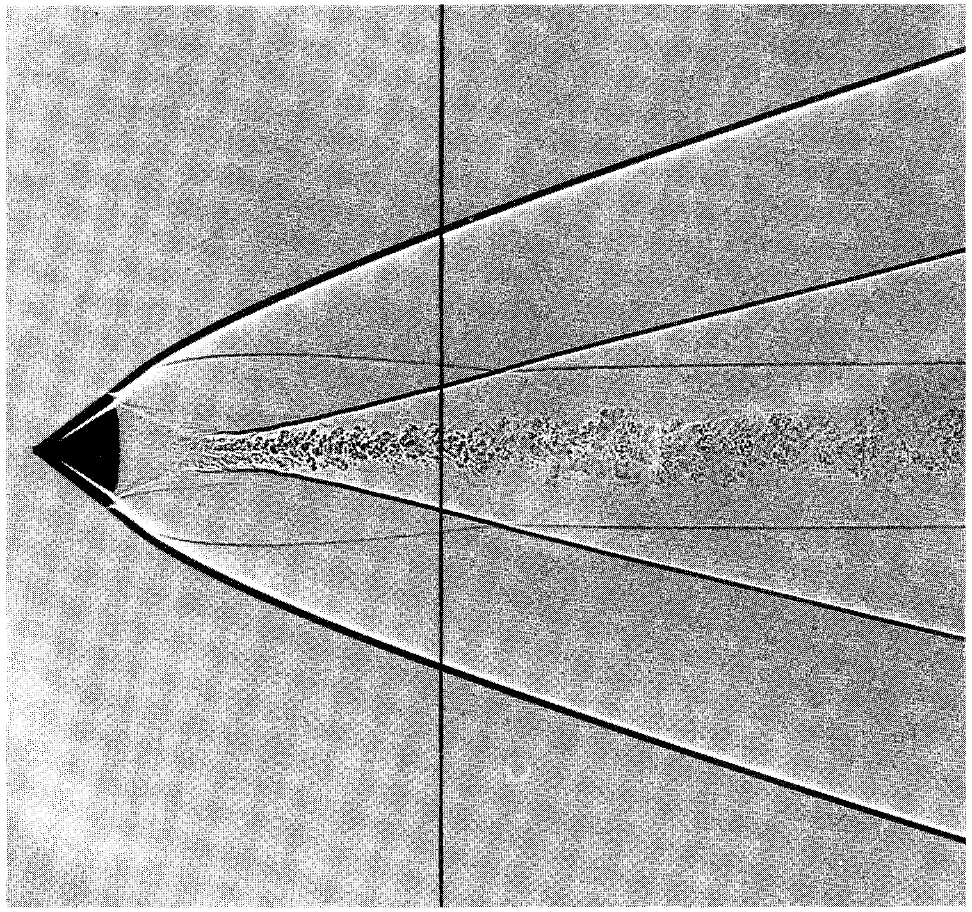
"The spot where it was heard to strike was so definitely located with reference to fences, buildings, and other landmarks, that they expected to find it readily when they searched in the meadow the next morning; but because of the uncut hay the search was difficult and nothing was found. They felt certain, however, of the approximate spot, and afterwards whenever work was done in the field a careful watch was kept for anything unusual. In July, 1923, while Louis A. Robin, Mr. Perry's son-in-law, was cultivating corn at the spot where they first searched, the cultivator struck a heavy object which proved to be the meteorite here described." (Perry, 1939)

The following points tend to disprove that the Seneca Township meteorite originated with the 1903 fireball. (1) The fireball was described as low in the sky and moving parallel to the horizon indicating a great distance from the ob-

servers. (2) Nothing was said about a cloud remaining in the sky where the fireball disappeared, as is standard for daytime observations within 50 miles of the fall area. (3) Immediate and subsequent searches revealed no evidence of impact. (4) The surface of the speciment suggests it fell longer than 20 years before it was found. (5) The statement about the fireball appearing "against the dark background of the clouds" is certainly erroneous. Possibly the fireball was seen through cloud cover. Also it may have been much higher in the sky than reported. (6) It is significant that the above account of the fireball was reported *after* the meteorite was found on the Perry land. At any rate, the evidence is not clear and certainly not conclusive.

Specimens of Seneca Township are in the following collections: United States National Museum, Nininger collection at Arizona State University, Chicago Natural History Museum, Harvard University, Perry collection at the University of Michigan, American Museum of Natural History, British Museum, and Michigan State University. Further information is reported in the following references: (1) Stuart H. Perry, Popular Astronomy, Vol. 47, p. 183-193, April 1939. (2) G. P. Merrill, Proceedings U. S. National Museum, Vol. 72, article 4, 1927.

Figure 17. Seneca Township meteorite. Size about 9″ x 7½″. Discovered in 1923. (from Popular Astronomy, March, 1939).



High velocity aluminum cone. Enlargement of photo on page 11. Ames Research Center, National Aeronautics and Space Administration.

VI

IN CONCLUSION . . .

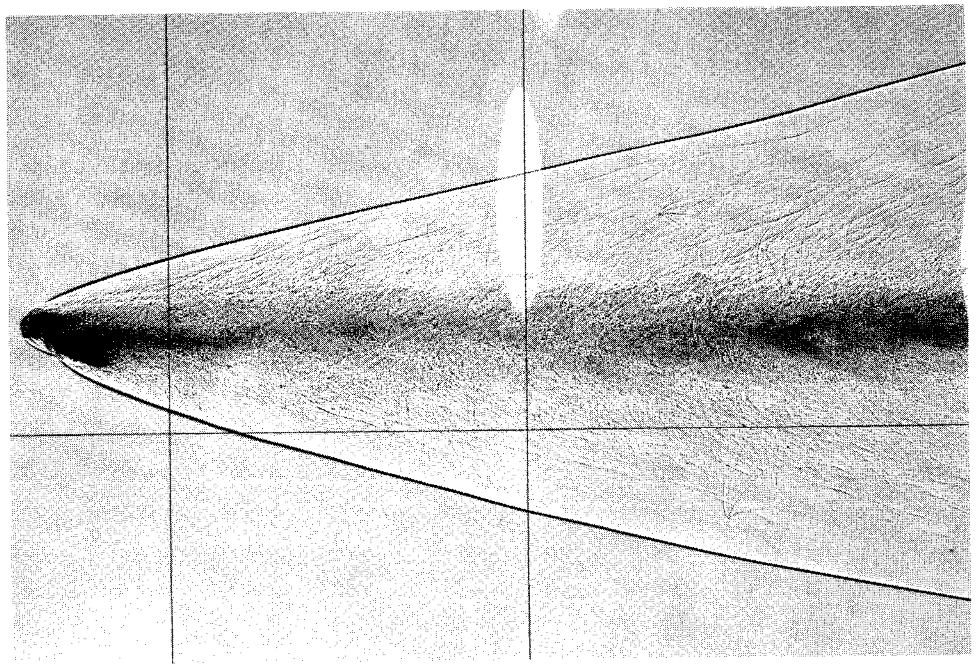
Meteorites have been worshipped, tabooed, buried with the dead, and used as weapons and tools. They also figure importantly in the shape and design of today's spacecrafts.

Meteorites are truly rare. Only eight are known in Michigan and about 1,600 throughout the world. Witnesses fortunate enough to view a prominent meteorite fall say it is one of the most memorable, if not startling, of all natural events.

Although accounts of falls appear in some of history's oldest records, little was known about their true identity until the beginning of detailed studies in the early 1800's. At one time, the belief was widely held that these events were a manifestation of God's wrath.

Today, astronomers, and geoscientists are particularly anxious to examine new specimens. Each find helps increase our understanding of the world we live on and its relation to the Universe.

As this booklet was going to press another spectacular fireball was viewed in Michigan skies. It was produced by a meteorite plunging into the earth's atmosphere above the region just north of Grand Rapids at 12:43 p.m. eastern daylight time, August 27, 1968. It traveled on a nearly north to south course, producing a fireball visible to thousands in the clear blue sky. A series of explosive and rumbling sounds were heard a few minutes later. Evidence strongly indicates that meteorites fell in the Grand Rapids vicinity. Fortunate circumstances and cooperation of the residents of the area may yield a scientific treasure—another Michigan meteorite.



Disintegrating graphite projectile. Enlargement of photo on page 11. Ames Research Center, National Aeronautics and Space Administration.

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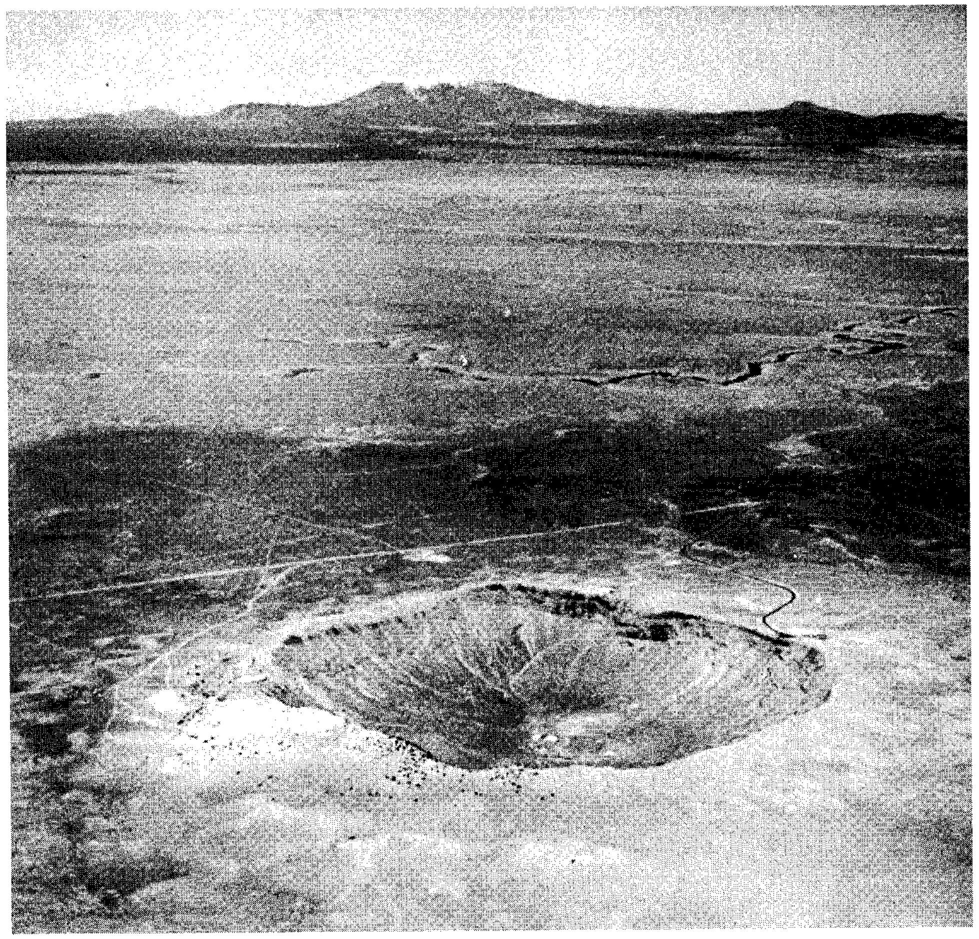


Barringer Meteorite Crater located near Winslow, Arizona

HISTORICAL BRIEFS

A "thunderstone" fell on the Island of Crete about 1478 B.C.

The black stone in the Kaaba at Mecca is believed to be a meteorite.

The "image" which was once in the temple of Diana in Ephesus may have been a meteorite. Acts 19:35.

More than one-thousand years ago the treasury of a Hittite king listed gold from a certain city, silver, copper and bronze from mines and "black iron of heaven from the sky."

On Nov. 16, 1492 about 11:30 a.m. a meteorite fell at Ensisheim in Alsace. Most of it is still preserved at the townhall in Ensisheim. This is the oldest meteorite in existence which was observed to fall. The emperor Maximilian referred to this meteorite fall as a sign of God directed against the Turks.

In 1794 E.F.F. Chladni wrote a scientific treatise maintaining that meteorites do, indeed, fall from the sky. He followed this with a book published in 1819, removing all doubt of the reality of meteorite fall.

On April 26, 1803 a shower of several thousand stones fell at L'Aigle, France. This event convinced the French Academy at Paris, and thus the scientific world, of the reality of meteorite fall. This date is often said to mark the beginning of the science of meteoritics.

Several stones fell at Weston, Connecticut on December 14, 1807. This event was studied and reported by Silliman and Kingsley of Yale. Thomas Jefferson said of this event, "I would more easily believe that two Yankee professors would lie than that stones would fall from heaven."

The meteorite crater known as "Meteor Crater" in Arizona was known to white men as early as 1871, but was not clearly recognized as a meteorite crater until about 40 years ago. It is also called "Barringer Meteorite Crater" in honor of Daniel Moreau Barringer who provided the evidence of its meteoritic origin.

On June 30, 1908 the most dramatic meteorite fall of historic times took place near the Tunguska River in Central Siberia. It was observed over an area more than 900 miles in diameter and produced detonations heard 600 miles from the place of fall. The shock wave killed reindeer and uprooted trees. Only minute meteorite fragments have been recovered. It has been suggested that this event was produced by a comet rather than an ordinary meteorite.

The second greatest meteorite fall of recorded times took place on February 12, 1947 in the Sikhote-Alin Mountains in Russia. Many small craters and impact holes were produced and more than twenty-five tons of meteoritic iron has been recovered.

Abstract

By way of introduction to the fascinating subject of meteorites, the author describes the dramatic sights and sounds accompanying two recent spectacular fireballs in the Great Lakes region. The reader is also taken on an imaginary journey with a meteorite in its fiery flight through the atmosphere.

Meteorites are among the rarest mineral objects found on earth. Their meaning and how they are identified and classified are discussed. Details on eight specimens found in Michigan are also provided. Many interesting accounts by actual observers are related and commented upon.

A convenient glossary of terms and a list of references complete this booklet.

Type Faces: Body is set in 10/12 pt. Times Roman. Quoted material is set in 8/9 Times Roman
Captions are 10/11 pt, Times Roman italic
Display type is Garamond Bold

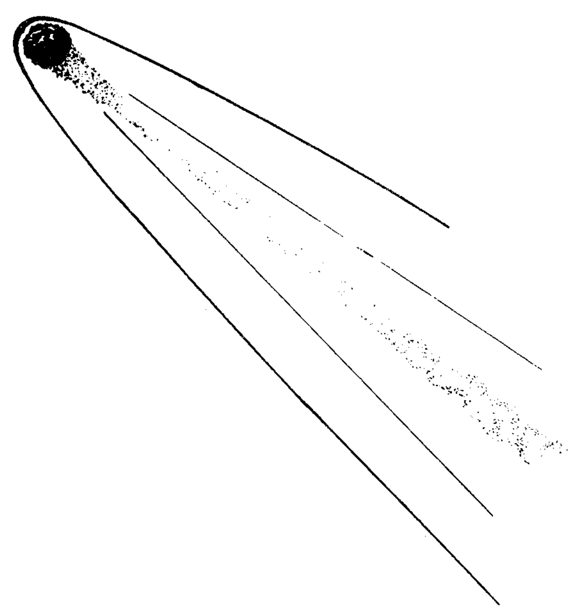
Presswork: Harris Single Color Offset

Binding: Signatures gathered, stitched and trimmed out on a Sheridan Stitcher

Paper: Body on 60# Prosperity Offset
Cover on 95# Currency Duplex Cover

(continued from inside front cover)

meteorite:	A natural solid object from space that retains its identity after having landed on earth. The term is also used to refer to the object in space before colliding with the earth.
meteoriticist:	Scientist who is a specialist in the study of meteors and meteorites.
octahedrite:	Most common type of iron meteorite. Contains bands of taenite and kamacite referred to as Widmanstatten structure.
octahedron:	A solid geometric form having eight faces.
pallasite:	Stony-iron meteorite in which the stony portion consist of olivine.
path:	The projection of the trajectory of a meteor or fireball against the sky as seen by an observer.
regmaglypts:	Shallow depressions resembling thumbprints found on the surface of many meteorites produced by ablation as the meteorite passed through the atmosphere.
siderite:	Another name for an iron meteorite.
siderolite:	Another name for a stony-iron meteorite.
specific gravity:	Ratio of the density of a material to water.
train:	Anything remaining along the trajectory of a meteor or fireball after the head of the meteor has passed. May be light, dust, vapor, ionization.
trajectory:	True line of flight of a meteor or fireball relative to the earth.
Widmanstatten figures:	Figures appearing on an etched surface of an octahedrite. The result of an intergrowth of kamacite and taenite produced as the meteorite parent body cooled in space. Named after Alois von Widmanstatten, who discovered them.



Michigan Geological Survey, Bulletin 5, METEORITES OF MICHIGAN, 1968