METEORITES
IN NORTH DAKOTA

by

Edward C. Murphy and Nels F. Forsman

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NORTH DAKOTA GEOLOGICAL SURVEY
John P. Bluemle, State Geologist
1998

On the Cover: Specimens of the Richardton (left) and Drayton (right) meteorites, two examples of stony meteorites found in North Dakota. This specimen of the Richardton meteorite has a very black (fresh) fusion crust because it was collected within days of its witnessed fall in 1918. The Drayton meteorite likely sat in a field for years before it was discovered as evidenced by the absence of a blackened "char" surface, and the presence of a slightly oxidized (rusted) reddish brown surface. Both meteorites reveal well developed ablation "dimples" on their surfaces due to the heat of atmospheric passage. The Richardton specimen measures 3 ¼ inches in length, and the Drayton is 6 inches long. Specimens shown approximately 70% of actual size.

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ABSTRACT

Meteorites are samples of early solar system materials. Meteoroids enter Earth's atmosphere daily but only a small fraction avoid vaporization in our atmosphere and reach the surface to become rock-size meteorites. Most meteorites that have fallen to Earth are pieces of asteroids. Very rarely, a meteorite has arrived from the crust of the Moon or Mars. Meteorites are classified into four main categories; chondrites, achondrites, stony iron, and iron based on their composition and texture.

Specimens of nine different meteorites have been found in North Dakota. Five of these are stony meteorites: Drayton; Richardton; Bowesmont (a); Bowesmont (b); and an unnamed meteorite near Bowesmont. Four of the North Dakota meteorites are irons: Freda; Jamestown; New Leipzig; and Niagara. The Niagara meteorite, found in 1879, was the first reported meteorite from North Dakota, and the Drayton meteorite, found in 1992, is the most recent as of this writing. The Richardton meteorite is by far the most studied and best documented meteorite to fall in North Dakota. Approximately 150 specimens with a combined weight of 220 pounds have been recovered from this meteorite. All known North Dakota meteorites have been studied by scientists, and representative specimens are housed in museums and universities throughout the world.

Five characteristics of most meteorites can be used to distinguish them from ordinary terrestrial rocks: 1) they easily attract a magnet; 2) they may feel heavier than a typical rock, but never lighter; 3) stony meteorites commonly contain very distinguishable spherical grains visible with a magnifying glass; 4) they may show a dimpled surface; and 5) if fresh, they may be coated by a thin black or brown char.

For decades, the prices paid for meteorite specimens remained relatively constant. In recent years these prices have escalated due to interest by private collectors. There is concern in the scientific community that these inflated prices may limit, and in some cases prevent, scientists form studying these specimens.

ACKNOWLEDGMENTS

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Our Solar System

In the early stages of the universe, the only matter in existence was hydrogen, and possibly some helium. It is from this matter that the first stars originated. First, hydrogen gathered into massive clumps through gravitational attraction. As an individual clump grew larger, it gradually compressed in on itself because of its own gravity. This compression squeezed atoms in the center of the proto-star together, causing frictional heating. If the clump was massive enough, that is, if it had enough of its own gravity, it could compress tightly enough to elevate interior temperatures to the fusion point of hydrogen. At that point, the star would ignite, or "turn on".

The first stars, and stars of today, operate in this way. The fusion of hydrogen in stars creates helium. This helium collects in the core of the star as a by-product or "ash" of the nuclear fusion of hydrogen. Hydrogen fusion continues to progress outward from the stellar center, leaving a growing collection of helium ash in the star's core. If the star is sufficiently massive, it may go on to also fuse the helium, which would produce carbon "ash" in the star's center. If carbon is fused, several elements are produced: oxygen, neon, sodium, and magnesium. If oxygen is fused, silicon is produced. Each subsequent fusion of these "ashes" collected in stellar interiors requires progressively higher temperatures; these elements are all progressively heavier and more difficult to fuse. So only the most massive stars can fuse silicon, which creates elements of the iron group. Still heavier elements are produced primarily during supernova explosions.

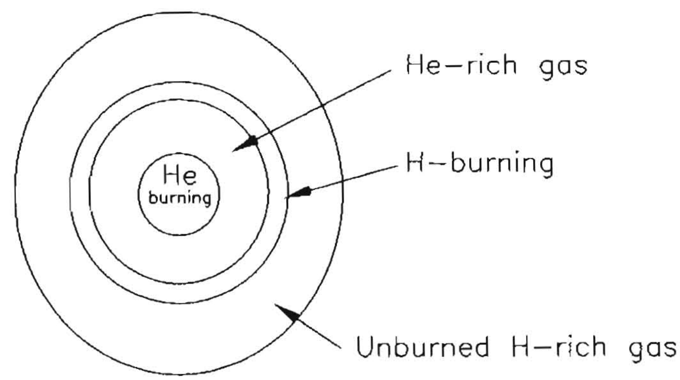


Figure 1. Diagram of fusion "shells" in a star.

Our sun is currently fusing only hydrogen, collecting helium "ash" in its core. It will eventually grow hot enough to also fuse its helium, but then it will "turn off" and slowly cool. Therefore, no elements heavier than carbon will be produced by our sun. But, spectroscopic examination of our sun decades ago revealed that it consists of all known natural elements. If our sun didn't manufacture those elements, where did they come from? The answer is that our sun is a second or third generation star. That is, our sun grew from the byproducts of previous very massive stars that exploded as supernovae.

Our sun grew from a "nebular cloud", which consisted of the gas and dust remains of exploded stars. And our sun developed from just one "clump" in this nebular cloud. The Hubble Space Telescope today shows us sites of new stars growing from nebular clouds. When material in a clump begins to gravitationally come together, it may also acquire some spinning motion.

As the growing mass continues to gravitationally contract, it will spin even more. Solids will begin to settle out along a midplane to form a spinning disk. In the case of our Solar System, these solids eventually constructively collided (accreted) to form planets, asteroids, and comets, all in orbit around the growing star (our sun) at the center of the disk.

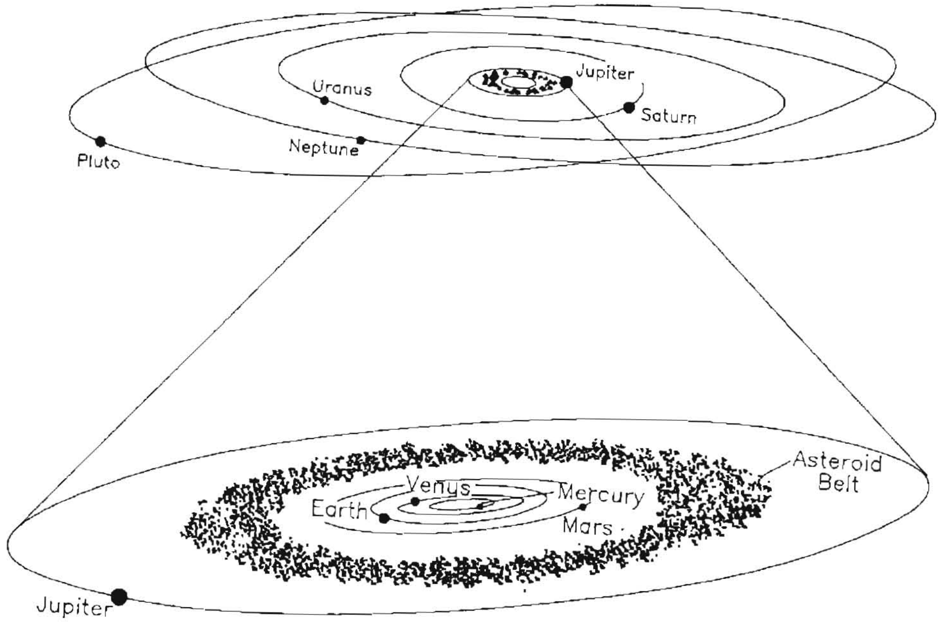


Figure 2. Relative position and orbit of planets in our solar system. Note the position of the asteroid belt between Mars and Jupiter.

Let's back up to examine the origin of planets. When the nebular cloud contracted to form the spinning disk, materials in orbit around the center of the disk were initially all moving in the same direction. In the case of our Solar System this was counterclockwise as viewed from "north". Thus neighboring particles of dust and ice would gently brush together, and therefore have a good chance of sticking together, growing larger particles through time. Eventually, objects grew large enough to gravitationally stir up their surroundings. This caused some objects to be pulled out of their original counterclockwise paths, and to be put on head-on collisional paths with other objects. At that point in time, conditions change from that of gentle sticking-together collisions, to one of survival of the biggest objects. Large objects then begin to grow even larger at the expense of smaller objects. Thus planets of considerable size were formed from a nebula of gas, dust, and ice.

What about the asteroid belt? It is situated between Mars and Jupiter, at the proper distance for a planet to have formed, but one never did. It is generally believed that the tremendous size of nearby Jupiter exerted gravitional stirring that kept objects smashing each other, instead of allowing a single dominant large object to survive. There are still gravitational influences affecting the distribution of rock debris within the Asteroid Belt, and occasionally debris is ejected from the belt.

Meteorites are samples of early solar system materials. They represent conditions in the portions of the spinning disk in which they formed. Most meteorites are pieces of asteroids. In fact, the solid iron meteorites can only have originated in the molten interiors of large asteroids. Stony meteorites represent the mantle and crust of asteroids. Many of the meteoroids that have fallen to Earth appear to be from a particular disrupted asteroid in the Asteroid Belt that is situated just right for gravitationally influences of other belt asteroids to deflect its debris toward a rendezvous with Earth. Some other meteorites probably derive from non-belt asteroides that intersect Earth's orbit. Thus, we do not have a completely random sampling of solar system material. Each new meteorite offers the possibility of something new and different. This is why it is so important for meteorites to be examined by scientists before they are cut up for sale by commercial outlets.

Meteoroids enter Earth's atmosphere daily. Most of these are microscopic meteorites that settle to the ground (or on us) slowly. Only the largest of these (a small fraction) avoid vaporization in Earth's atmosphere and reach the surface to become rock-size meteorites.

Meteorite Classification

Most meteorites are thought to be smaller pieces of asteroids created by the collision of two or more of these larger objects. Asteroids formed around the Sun at the same time the planets and Sun were forming. Therefore, of the 3000 or so meteorites that have been discovered, most are as old as Earth and the solar system and have overall compositions similar to the Sun. Very rarely, a meteorite will be derived from the crust of the Moon or the planet Mars. These meteorites are believed to have been ejected into space as a result of crater-forming impacts.

As with other rock samples, meteorites are classified according to their composition and texture. There are four primary meteorite classifications:

* Chondrites–similar in composition to the mantles of the planets, most meteorites belong to this class.

* Achondrites–similar to terrestrial basalts; the meteorites that originated from the Moon and Mars are in this class.

* Stony Iron–a mixture of iron and stony material.

* Iron–composed primarily of iron and nickel.

These four major categories are further subdivided into an additional 36 classes based on subtle differences in element concentrations, mineralogy, and texture. For example, chondrites are divided into ten classes (CI, H, LL, etc.) and irons into 14 classes (IAB, IC, IIAB, etc.) (Sears and Todd, 1988). In addition to these classifications, meteorites are typically named after the closest inhabited area. In North Dakota, the few meteorites that have been found have been named for the closest city or town. In sparsely populated areas such as Antarctica, meteorites are named for topographic features or given unique numbers.

North Dakota Meteorites

In 1968, Frank Karner wrote a report for the North Dakota Geological Survey (Miscellaneous Series 37) on the meteorites of North Dakota. He cited five known North Dakota meteorites (Freda, Jamestown, New Leipzig, Niagara, and Richardton) and noted that a state of similar size (Kansas) had reported 53 meteorites. As Karner pointed out, most of the Kansas meteorites had been found after a statewide meteorite search program had been initiated. Since Karner's report, only four meteorites (Bowesmont (a,b), an unnamed one near Bowesmont, and Drayton) have been reported in North Dakota.

The official catalog for meteorites is the British Museum of Natural History's Catalogue of Meteorites (Graham and others, 1985). This book lists six meteorites from North Dakota; Bowesmont, Freda, Jamestown, New Leipzig, Niagara, and Richardton–the Drayton meteorite has recently been registered. At least four references to additional North Dakota meteorites (Bowbells, Buffalo, Carrington, and Edgeley) are present in old newspaper clippings or old correspondence (*Figure 3*). There are no references to these four potential meteorites in the scientific literature. If these meteorites exist, they are likely in private collections. Many meteorite dealers have web sites on the Internet. Several universities, museums, and meteorite dealers post a listing of their meteorite specimens on these web sites. A thorough search of these sites was conducted but no specimens were listed from these four potential meteorites.

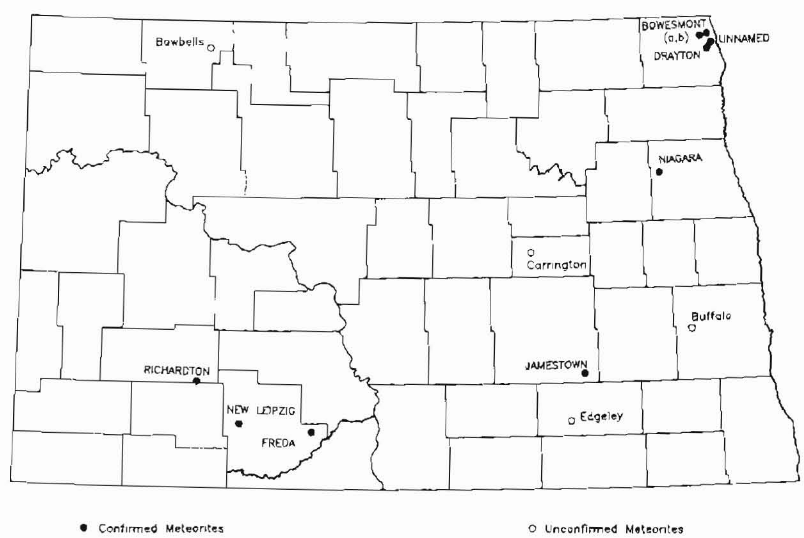


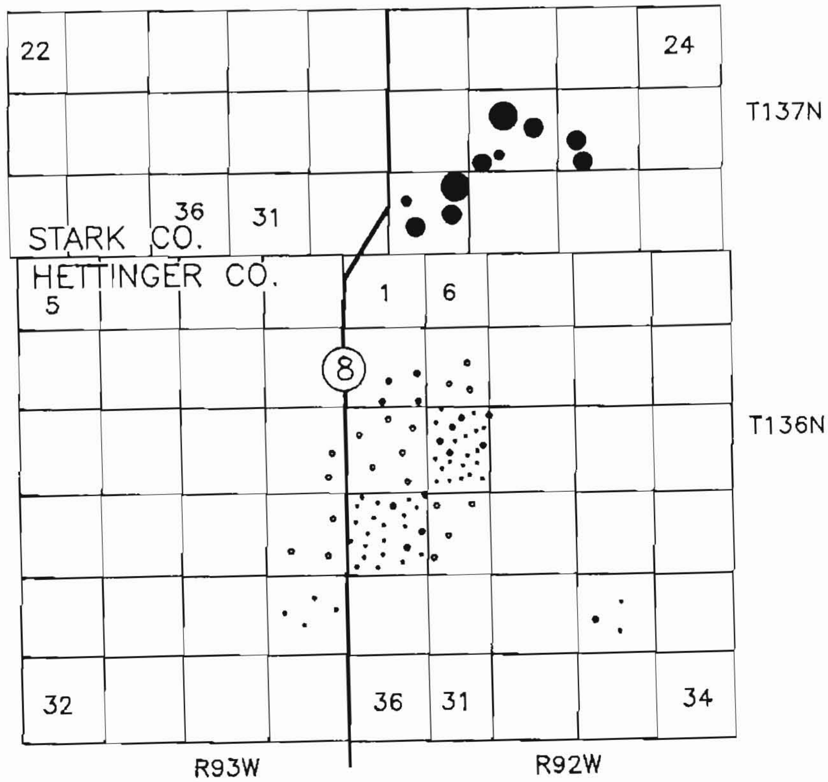
Figure 3. Where meteorite specimens have been found and where unconfirmed meteorites have been reported in North Dakota.

STONY METEORITES OF NORTH DAKOTA

Richardton Meteorite

The Richardton meteorite is by far the best known and best documented meteorite to fall in North Dakota. At 9:48 pm (mountain time) on June 30, 1918, a stony meteorite fell between Richardton and Mott (Quirke, 1919). Pieces of the meteorite were scattered along a 45-square-mile area along the Stark and Hettinger county lines (*Figures 4-6*). Such a large area of distribution is not unusual for stony meteorites which tend to break into many pieces high in the atmosphere (Moore, 1971). The fall was witnessed by several local farmers as well as individuals in Mandan, Dickinson, Hettinger, and

Figure 4. General distribution of Richardton meteorite specimens along the Stark--Hettinger county line. The meteorite traveled from southwest to northeast. Following breakup, the inertia of the largest pieces carried them furthest north. Modified from Quirke (1919) and Nininger (1952).



Relative size of Quirke's meteorite specimens

Areas where additional specimens were likely found by Treganza or Nininger.

Figure 5. A view of the northern area where the Richardton meteorite fell. This area is predominantly farm land.

Lemmon, South Dakota. T.T. Quirke, a professor of geology at the University of Minnesota and a graduate of the geology department at the University of North Dakota, studied the stony meteorite and determined from interviews that the meteor was seen over an area of more than 400 square miles and the noise created by the breakup up of the meteorite into chunks in the atmosphere, described similar to an intense explosion, could be heard over an area at least 250 square miles.

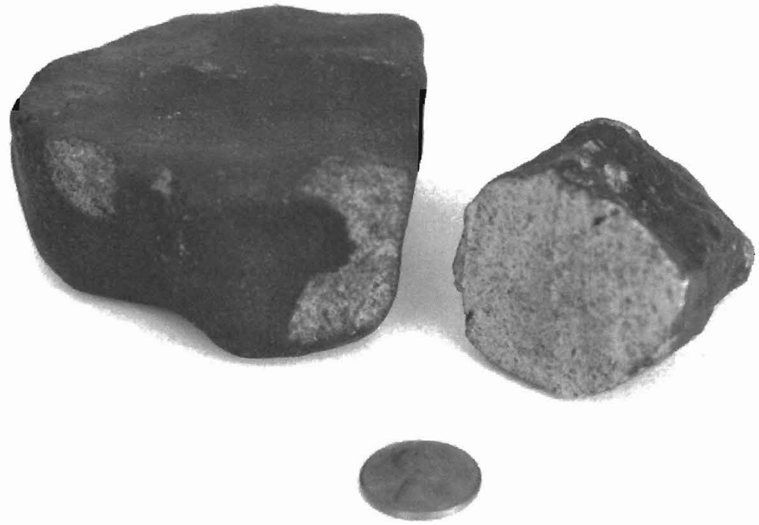


Figure 6. Specimens of the Richardton meteorite originally purchased from a landowner by T.T. Quirke for the University of Minnesota. These Specimens, housed in the collection of the Department of Geology and Geological Engineering at the University of North Dakota, were purchased from Quirke by A.G. Leonard. A penny for scale.

State Geologist A.G. Leonard was doing fieldwork in western North Dakota when the meteorite fell but did not hear about it until he got back to Grand Forks that fall. The president of the Merchants State Bank in Richardton, acting as a broker for several pieces of the meteorite, wrote to Leonard in early August but due to Leonard's absence did not get a response until late September. Probably owing to this delay and a suspected lack of interest, the president of the bank contacted the University of Minnesota which in turn sent Professor Quirke out in early November to obtain specimens for their collection. In the meantime, a mineral collector from Iowa arrived in the area in September and purchased approximately 60 pounds of meteorite specimens. By the fall of 1918, Quirke estimated that approximately 100 specimens, with an approximate cumulative weight of 200 pounds (including those purchased by the Iowa collector), had been recovered in the area. Specimens of the Richardton meteorite are housed in at least a dozen museums and universities throughout the country (Table 1). Several specimens are also housed at the British Museum and others likely have been scattered to other institutions throughout the world. Nine of the specimens collected by Quirke were retained by the University of Minnesota until the mid-1960s when they were deposited at the U.S. Natural History Museum (E.Calvin Alexander, correspondence, 1/20/98).

Many of the relatives of those who witnessed the meteorite fall (Miller, Kuntz, Loran, Friedt) still live on or near the family farm. Over the years, these families have grown accustomed to scientists and interested hobbyists visiting the area in search of meteorite specimens. Harvey Nininger, a world famous meteorite hunter, may have conducted field investigations of the Richardton area during the 1930's. Although his files, housed at Arizona State University, fail to mention time spent in North Dakota, Nininger states in his book *Out of the Sky* (page 159) that "The Richardton, North Dakota, fall of 1918 was investigated during the period from 1931 to 1936." He discovered an additional 44 specimens with a combined weight of 40 pounds bringing the total known Richardton specimens close to 150 and the total retrieved weight to around 220 pounds (Nininger, 1952). Michael McGehee, Arizona State University, searched Nininger's files and found that they contained letters and papers indicating that Nininger purchased Richardton specimens from others but does not indicate he searched the area himself (correspondence, 3/13/98). When a scientist familiar with Nininger's fieldwork was asked about this apparent discrepancy he stated that Nininger often took little or no field notes. If Nininger was in the area during the 1930s, he likely combed the fields and pastures with a trailer-mounted magnetic apparatus in an attempt to attract specimens of this slightly magnetic stony meteorite. If Nininger conducted such a study, another magnetic survey of the area would be unlikely to find additional specimens.

There is an another reason a meteorite survey of the area may not be very productive. As will be discussed in more detail later, as soon as meteorites land on Earth they begin to weather. Weathering is accelerated in hot, humid climates and slowed in arctic, desert climates. For example, Nininger (1952) collected some stony meteorites in Arizona twenty years or so after they fell that were so badly weathered that they crumbled in his hand. In contrast to this, Nininger noted that the specimens of the Richardton meteorite collected 13 to 18 years after they had fallen were generally firmer than those specimens that were collected soon after it fell. He attributed this phenomenon to cementation by the oxidized granules of metal spread throughout the meteorite. He speculated that this condition was likely temporary and additional oxidation would cause the specimens to crumble. Therefore, any specimens discovered in the fields today, some eighty years after the fall, would likely be in very poor shape and may be scarcely recognizable. Undeterred by this, others have continued to search for the Richardton meteorite over the years. In 1967, the Bismarck Tribune (July 28, 1967, p.6) noted that a scientific group from Virginia (Eastern Meteorite Investigations) was urging families in the area to search their homes for pieces of the Richardton meteorite that had been kept as curios. The group offered to purchase meteorite specimens at $18.00 per pound.

The Richardton meteorite is very important scientifically because the fall was well documented and the numerous specimens have allowed many scientists to study its chemistry and mineralogy. In 1919, T.T. Quirke wrote the first scientific article on the Richardton meteorite. The article was based on eyewitness accounts of the fall and descriptions of the meteorite specimens. Quirke provided a scientific first when he noted the presence of elemental copper in the Richardton specimens, the first time this metal had ever been found in a meteorite. In addition to Quirke's article, there have been over thirty scientific articles concerning the Richardton meteorite. Another important scientific first involving the Richardton meteorite had to do with extinct radioactive nuclides. Harrison Brown, in 1947, had predicted that isotopic fossils of extinct radionuclides from the earliest history of the solar system might be found in meteorites. In 1960, J.H. Reynolds, of Berkeley, confirmed this experimentally by finding an isotope of xenon (Xe^{129}) in the Richardton meteorite (Mason, 1962). Reynold's 1960 discovery of an isotopic fossil of an extinct isotope in the Richardton meteorite opened a whole new branch of experimental science, cosmochronology, the chronology of the formation of the elements and the solar system.

Bowesmont (a, b) Meteorites

In 1962, a stony meteorite weighing 2.27 kilograms (approximately 5 pounds) was discovered near Bowesmont in Pembina County (Huss, 1976; Graham et al., 1985). In 1972, an additional 1.3 kg (2.8 pound) specimen of this meteorite was found in this same area (Table 1). Over the years, three additional specimens were found in this area. Four of the five specimens were found by Allan (Sandy) McDonald and the fifth by a renter on McDonald's land. Everyone knows someone like Sandy McDonald, a keen observer who instantly sees objects on the ground that others have passed over for years. All of his life Sandy has been an avid collector of things: artifacts, rocks, antiques, etc. According to Mrs. Flora McDonald, it was a frequent occurrence to see Sandy leaning out over the edge of his open air tractor looking for rocks and artifacts. He may not have had the straightest furrows in the county, but

Table 1. Museum and university holdings of North Dakota meteorites.

BOWESMONT (a & b) (stony meteorites)

Olivine-hypershene L6 Chondrites.

Bowesmont (a)—a mass of 2.27 kg was found in 1962 and in 1991 a 226.3 g specimen was recovered.

Bowesmont (b)— a mass of 342 g was found in 1972 and 1380.5 g mass was found in 1975.

Specimens	
344 g	Max-Planck-Institute, Main
116 g	U.S. Natural History Museum, Washington, D.C.
96 g	American Museum of Natural History, New York.
121g	Arizona State University, Tempe.
128.5g	British Museum of Natural History, London.

These collections represent 5% of known meteorites.

UNNAMED METEORITE near Bowesmont (stony meteorite)

A mass of 640.5 g was found in 1986 in southeastern Pembina County. This specimen is housed at the American Meteorite Laboratory.

DRAYTON (stony meteorite)
H4-5 Chondrite

A mass of 2.35 kg was found in July, 1982. Nels Forsman is in possession of the entire specimen.

FREDA (iron meteorite)
Ataxite, nickel rich (IIICD)

A mass of 268 g was plowed up in a field near Freda in 1919.

Specimen	
255 g	U.S. Natural History Museum, Washington, D.C.

This collection represents 95% of known meteorite.

JAMESTOWN (iron meteorite)
Octahedrite, fine (0.26mm) (IVA).

A 4kg mass was found in 1885, 15-20 miles south of Jamestown.

Specimens	
1563 g	British Museum of Natural History, London.
581 g	Field Museum of Natural History, Chicago
329 g	U.S. Natural History Museum, Washington, D.C.
144 g	Paris
128 g	Humbolt University, Berlin.
103 g	Tubingen
97 g	Natural History Museum, Vienna.
91 g	American Museum of Natural History, New York.
86 g	Harvard University, Boston.
52 g	Vatican College, Rome
51 g	Strasbourg
45 g	Ottawa
36 g	Bonn
7 g	Rome

These specimens represent 83 % of known meteorite.

NEW LEIPZIG (iron meteorite)
Octahedrite, coarse (2.6mm) (IA).

One 20 kg mass was found in 1936 in a field one half mile south of New Leipzig (T133N, R90W section 2 swsene).

Specimens	
17.9 kg	U.S. Natural History Museum, Washington, D.C.
553 g	Field Museum of Natural History, Chicago.
183 g	Calcutta
19.5 g	British Museum of Natural History, London.
19 g	Arizona State University, Tempe

These collections represent 93% of the meteorite.

NIAGARA (iron meteorite)
Octahedrite, coarse (1.4mm) (I).

A small mass of 115 g was found near Niagra in 1879.

Specimens	
25 g	Field Museum of Natural History, Chicago.
19g	Yale University,
16g	British Museum of Natural History, London.
8g	Vatican College, Rome.
7g	Natural History Museum, Vienna.
3g	Humboldt University, Berlin.

These collections represent 68% of the known meteorite.

RICHARDTON (stony meteorite)
Olivine-bronzite chondrite (H5), veined.

The fall was wintessed and 90.718 kg of meteorite (140+ specimens) were collected between 1918 and 1936.

Specimens:	
14.5 kg	Michigan University
10.4 kg	Arizona State University at Tempe
10.1 kg	British Museum of Natural History, London
8.3 kg	American Museum of Natural History in New York
5.1 kg	U.S. National Museum in Washington D.C.
3.5 kg	Field Museum of Natural History in Chicago
3.2 kg	University of Illinois
2.58 kg	Harvard University
1.0 kg	Philadelphia Academy of Natural Science
1.0 kg	Yale University
0.39 kg	University of California at Los Angeles
37.82 g	University of New Mexico
490.3 g	University of New Mexico
	University of North Dakota

These collections represent 67% of meteorite.

Sources: Buchwald, 1975; Graham et al., 1985; Huss, G.R., 1998, written communication.

Sandy seldom let a stone go unturned. The first meteorite he found drew his attention because it looked "burnt". As a result of his diligence, five specimens belonging to three distinct meteorite falls were found in a relatively small area of Pembina County (Gary R. Huss, correspondence, 4/4/98). McDonald found one of these specimens in a rockpile at the local dumpground. What is interesting is that three specimens, representing two distinct meteorite falls were found in the same quarter section of McDonald's land in Joliette Township. In the 1960s, Glenn Huss (at the time, Director of the American Meteorite Laboratory) examined these specimens and was quoted in the Cavalier Chronicle (an undated clipping, circa 1960s) as saying that based on its appearance, the specimen found in 1962 likely had fallen 50 years or more prior to its discovery. Huss visited with area farmers and asked them to keep an eye out for unusual rocks in their fields but this apparently did not result in additional finds.

Unnamed Meterorite near Bowesmont

A meteorite specimen found by Sandy McDonald in southeastern Pembina County has not been classified or given an official name. The specimen, a stony meteorite, weighs 640.5 grams and is in the possession of the American Meteorite Laboratory (Gary R. Huss, correspondence, 4/4/98).

Drayton Meteorite

In the early 1990s, Phil Raney, a nephew to Sandy McDonald, found a 2.35 kilogram (5 pound) meteorite specimen on his farmstead located approximately half way between the towns of Bowesmont and Drayton. Nels Forsman obtained the specimen a few years ago and recently registered it as the Drayton meteorite (*Figure 7*). The Drayton meteorite is a common stony meteorite. Forsman compared the chemistry and mineralogy of the Drayton meteorite to that of the Bowesmont (a,b) meteorites and determined that they represented different falls. The Drayton meteorite has prominent dimples and its reddish brown surface indicates that it had fallen some years prior to its discovery.

Figure 7. Two views of the Drayton meteorite (a) highly dimpled surface and (b) cut surface displaying small metal (nickel-iron) flecks.

Freda Meteorite

In 1919, Henry G. Meyer, of Shields, plowed up a 268 gram (9.5 ounces) iron meteorite approximately two miles southwest of Freda in Grant County (T133N., R84W. southeast quarter of section 24). In 1939, the specimen was purchased from Meyer by the U.S. National Museum (Table 1). The fusion crust (a thin layer on the outer surface of the meteorite that forms when a small portion of the rock vaporizes coming into Earth's atmosphere) of the Freda meteorite is well preserved and the meteorite has the general appearance of a spent bullet due to its dimensions (4.5 x 4.0 x 3.0 cm --1.7 x 1.6 x 1.1 inches) and well-rounded leading edge (*Figure 8*). The Freda meteorite is thought to represent the entire mass of one of the smallest meteorites ever found (Buchwald, 1975). Buchwald estimated from the small amount of weathering that the meteorite had undergone that it had fallen roughly 50 to 500 years before its discovery. This meteorite contains an unusually high amount of nickel, approximately 23 percent (Henderson and Perry, 1942).

Figure 8. The Freda meteorite is thought to be one of the smallest intact meteorites ever found. Scale bar 20 mm. Photograph courtesy of the U.S. Natural History Museum in Washington D.C. (U.S.N.M. specimen no. 1342, S.I. negative no. 258A).

Jamestown Meteorite

In the fall of 1885, an iron meteorite weighing 4kg (8.8 pounds) was found in a shallow, slanting hole by a railroad worker within five feet of the James River Valley branch of the Northern Pacific Railway (Huntington, 1890). The description of the hole led Huntington to surmise that the fall had occurred relatively recently, likely sometime in the 1800s (*Figure 9*). The exact locality of the find is not known, but was reported to be 15 to 20 miles southeast of Jamestown, likely near the present town site of Montpelier in Stutsman County. The find was purchased by O.W. Huntington and then cut and distributed to various museums (Table 1). The meteorite was slightly curved and had the general appearance of a low bowl with the approximate dimensions of 64 x 32 x 5 cm (10 x 5 x 1 inches) (Buchwald, 1975). Given its curvature, Huntington suspected it was an outer piece or scale from a larger, rounded meteorite. The Jamestown meteorite contains approximately 7.5% nickel and is somewhat unique because it is relatively highly malleable. Huntington noted that when he held the edge of the meteorite in a vise, "the mass could be readily bent back and forth with the hand, and it invariably broke like a soft semi-solid material. Moreover, the iron was so malleable that it could be readily rolled out into thin ribbon in the cold".

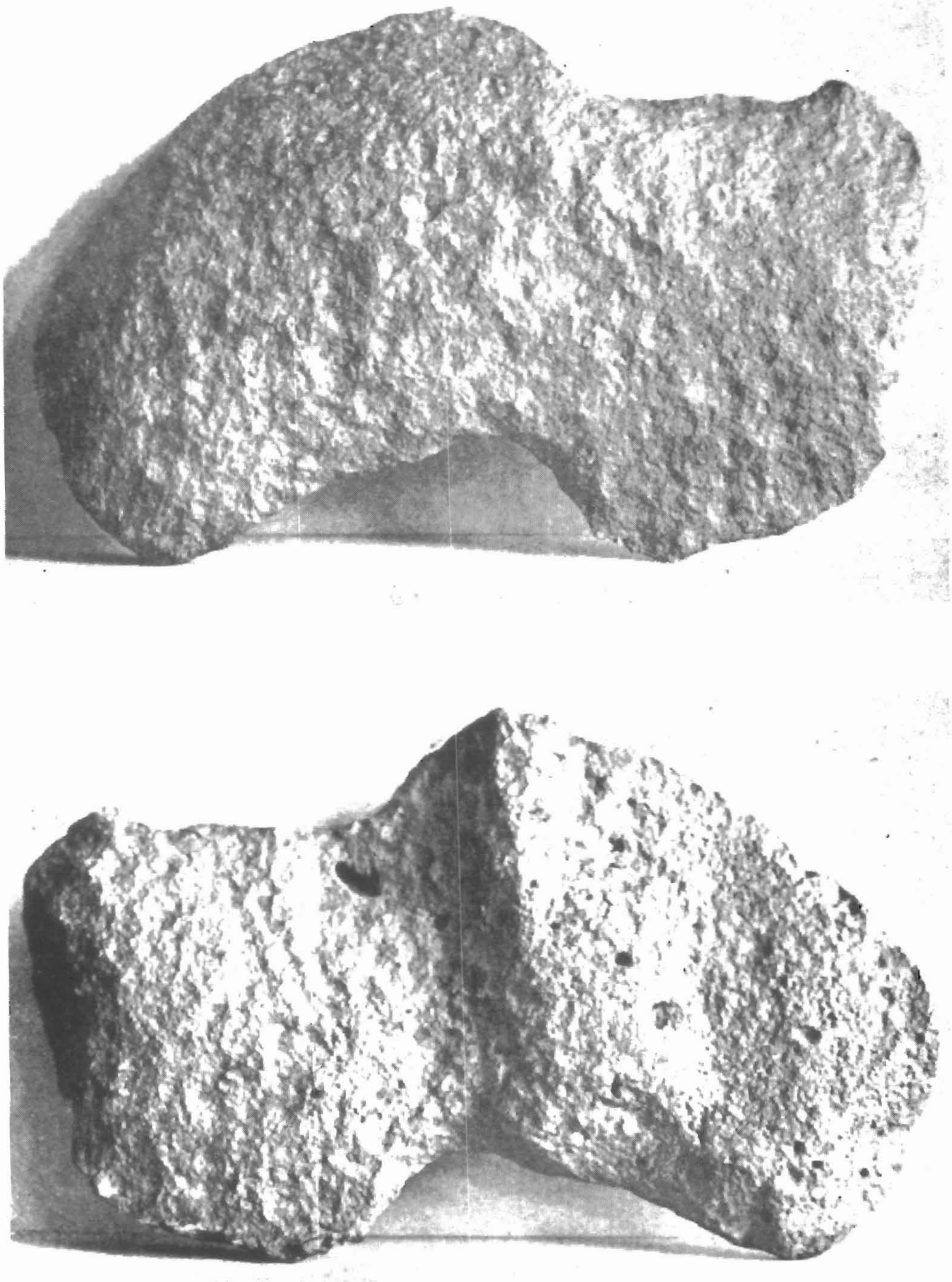


Figure 9. Top (upper photo) and bottom views of the Jamestown meteorite. Due to its shape, the Jamestown meteorite is thought to be a part of a much larger meteorite. Photographs obtained from O.W. Huntington's 1889 article which appeared in the *Proceedings of the American Academy of Arts and Sciences*, no. 25. Reprinted by permission of the American Academy of Arts and Sciences.

New Leipzig Meteorite

In 1936, Daniel Buckwitz, Jr. found a 20 kg (44 pounds) iron meteorite on his farm near New Leipzig in Grant County (T. 135N., R. 90W. northwest quarter of section 14). The meteorite had dimensions of approximately 28 x 15 x 11 cm (11 x 6 x 4.7 inches). It has a highly dimpled surface which resulted when portions of the meteoroid's surface boiled away due to the heat of atmospheric passage (Figure 10). These dimples, called regmaglypts, are common in iron meteorites. Portions of the meteorite are rust colored, but apparently the specimen had undergone very little weathering before it was discovered (Buchwald, 1975). The U.S. National Museum purchased the specimen for $150 in 1937. Mr. Buckwitz was very appreciative of the money, coming as it did during the Great Depression. He proclaimed in a letter to the Smithsonian "The discovery of this meteorite on my farm and the sale of it is a blessing from Heaven for me and I thank God for it." The Smithsonian has kept 90 percent of the meteorite intact and distributed specimens cut from one corner to a handful of museums (Table 1). Buchwald estimated the meteorite contained about 6.5% nickel.

Niagara Meteorite

In August 1879, F. Talbot picked up a small iron meteorite as he was collecting rocks and minerals on his father's farm a few miles southeast of Niagara in Grand Forks County. The specimen weighed 115 grams (4.1 ounces) and was reported to be very much oxidized, brownish-black in color and showed no trace of the original fusion crust (Preston, 1902). The Ward's Natural Science company purchased the specimen from the family and distributed it to museums throughout the world (Table 1). The specimen appears to have been a complete meteorite but had undergone surface corrosion prior to its discovery (Buchwald, 1975).

UNCONFIRMED METEORITES

Bowbells

In August, 1910, Ike Ross reportedly witnessed a meteorite striking a deserted sod shack approximately 4 miles south of Bowbells. According to the Bowbells Tribune (July 22, 1910, page 3) "*Uncle Ike Ross, while sitting alone at the backdoor of his farm home four miles south of Bowbells on Sunday night last had his attention attracted by a ball of fire descending from the heavens and he had not long to watch the thing before he could plainly hear the swish made by it in passing through space and it less time than it takes to tell it, it struck the deserted sod shack near by and the force of its descent drove it through several feet of the side of the sod shack and it became imbedded in the earth underneath to the depth of at least two feet*". Ross brought the rock to Bowbells the next day and the reporter noted that the four pound rock was burnt perfectly black and emitted a strong odor of sulfur. He was offered money on the spot for the specimen but refused to sell it and spoke of sending it to the "State University" for examination. There is no mention in the Geology Department records that the rock was ever sent to UND. Ike Ross apparently died a few years after the discovery and we were unable to trace his wife Anna or their six children through records at the ND Heritage Center. There is no mention of this meteorite in the scientific literature. A recent article on this story in the Burke County Tribune has encouraged people to come forward with rocks that they suspected might be meteorites but so far no meteorites have been confirmed.

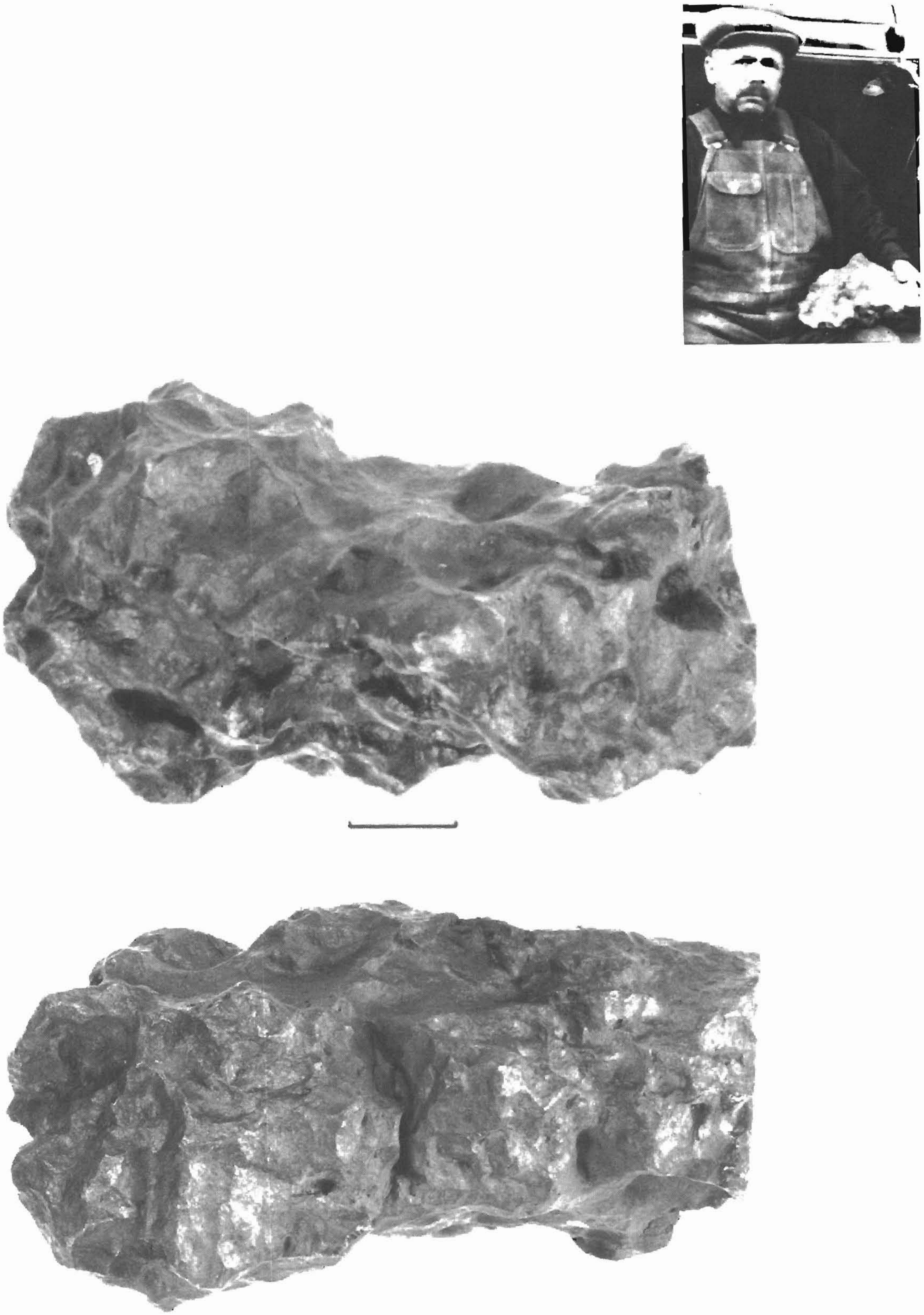


Figure 10. Side views of the New Leipzig meteorite. The iron meteorite contains very prominent regmaglypts (dimples). Photograph courtesy of the U.S. Natural History Museum (N.M.N.H. specimen no. 1210, S.I. negative nos. 1631A (top) and 1631D). Scale bar is 4 cm. The insert photo shows Daniel Buckwitz, Jr., an avid rock collector, holding the New Leipzig meteorite that he found on his farm in 1936. The photograph of Mr. Buckwitz is from the 75th commemorative anniversary volume on New Leipzig (*New Leipzig, North Dakota 1910-1985)*, p. 399.

Buffalo

On April 2, 1894, the Bismarck Daily Tribune (page 3) reported that a meteorite estimated to weigh several tons fell at 1:00 am in the town of Buffalo in Cass County (Figure 11). The meteorite reportedly struck the cupola of the elevator literally crushing the entire building. The article contains a rather unbelievable description of the event: "*A report of the affair says that after the crash, which made a report like the explosion of a powder magazine–a sound which was heard for miles around–an illuminated column, having all the color of the rainbow, shot heavenward and remained in place for nearly half an hour, lighting a space at least a mile square...*" The meteorite was reported to be in the shape of a flattened egg and criscrossed with green stripes an inch or so wide. A search of area newspapers failed to find any other references to this bizarre story in and a meteorite has not been reported from this area in the scientific literature. Given the date of the article, it is possible that the Tribune fell victim to an April fools joke by reprinting an April 1 article from an eastern North Dakota newspaper. If so, the joke was still in effect over 100 years after it first appeared because we spent time trying to validate this story.

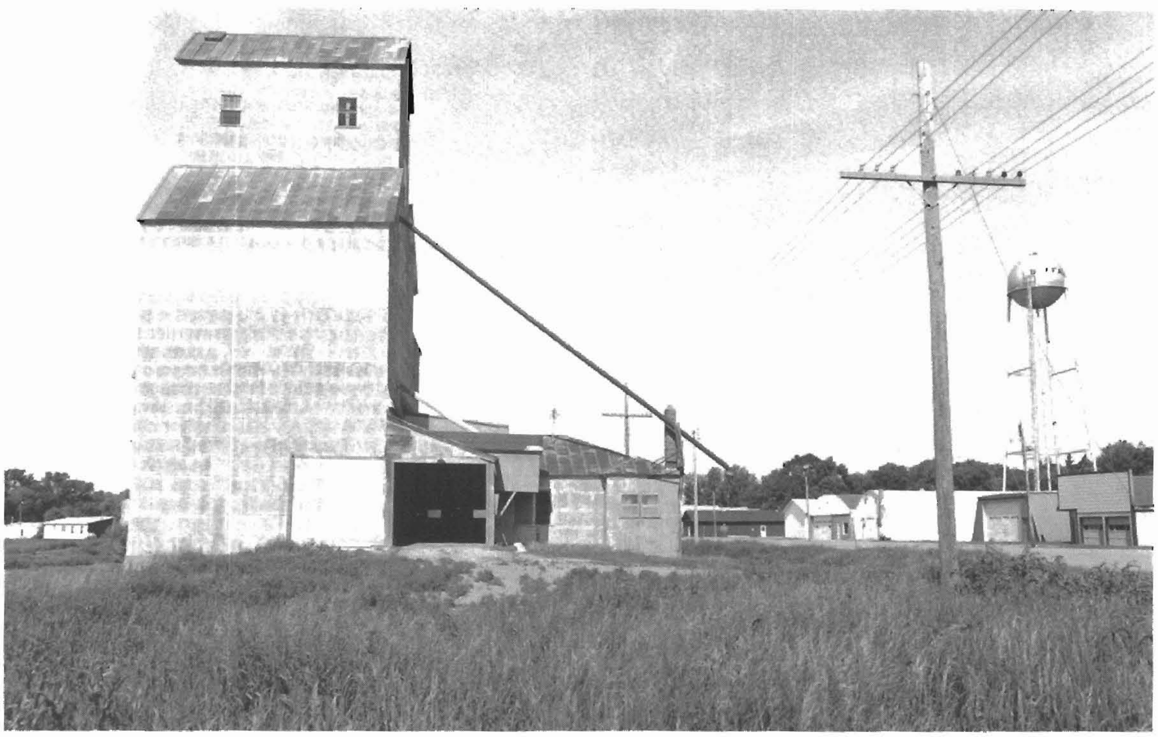


Figure 11. A recent photograph of the Peavey Elevator in Buffalo, North Dakota. Buffalo was the site of a bizarre newspaper story of a meteorite destroying an elevator in the 1890s.

Carrington

On January 13, 1910, the Carrington Weekly carried an article entitled "*Five Foot Meteor Strikes Near Guptil, Buries Itself Six Feet Deep in Ground and Sizzles for a Day*". The meteorite was reported to have fallen four miles northwest of Carrington at 2:00 am on January 10, 1910. Although initially reported to be over five feet in diameter, it was later said to be only 3 feet, weigh approximately 600 pounds, and have the appearance of iron ore (Carrington Weekly Independent; January 27, 1910; p.1). The brilliant light from the fall was said to have engulfed the countryside for miles and was witnessed by at least two local families. The meteorite was reported to have stayed white hot for a full day after it fell. Citizens of Carrington expressed interest in putting it on display on the courthouse lawn but instead it was kept at Beck's Clothing Company store where it attracted hundreds of visitors (Courtnay Gazette; December 22, 1910; p.1). It was later moved to the sidewalk in front of the store and was reported missing in December of that year. The Fargo Sunday News (December 18, 1910, p.15) carried the story under the title "*Carrington Meteor Vanishes from Sight, Rock that Attracted Attention of Scientists has Disappeared*". It was speculated that workers filling a sewer line in front of the store used the meteorite for backfill. Others thought that it had been stolen. The discovery of the meteorite had apparently been picked up by newspapers across the country and even journals such as Scientific American.

There are no references to a Carrington or Guptil meteorite in the scientific literature. One newspaper account briefly mentioned that there was a rumor going around that the rock never fell (Carrington Weekly Independent; January 27, 1910; p. 1). It is quite possible that this story was a hoax. The report that the rock was white hot for twenty-four hours certainly does not seem plausible since most meteorites are believed to be fairly cool by the time they reach the surface (Adrian Brearley, personal communication, 1998). The rock may well have been a glacial erratic that was unearthed in the Guptil area.

Edgeley

In a November 10, 1918 letter to State Geologist A.G. Leonard, T.T. Quirke mentioned that he had heard of a meteorite near Edgeley, North Dakota. There is no further mention of the possible meteorite in their subsequent correspondence nor in Quirke's article. No meteorites from this area have been reported in the scientific literature.

METEORITES IN COAL

A.A. Sicree and D.P. Gold, geologists at Pennsylvania State University, recently began a study to identify iron meteorites in coal beds (Figure 12). Iron meteorites typically rust away on Earth's surface within twenty or thirty years unless they land in a desert environment where they may last for thousands of years. As Sicree and Gold point out, meteorites have collided with Earth throughout geologic time but meteorites are very rarely found preserved in sedimentary rock (Childress, 1996). The geologists theorize that the reduced states that exist in coal and peat and the presence of sulfide ions may minimize deterioration of these meteorites by forming a protective coating of pyrite. Based on the average mass of meteorites that strike Earth per day (100 to 1,000 metric tons) and the approximate rates of coal accumulation (300 to 3,000 years per foot), Sicree and Gold have calculated that every million short tons of coal should yield 300 grams of recoverable magnetic meteorites (assuming that 99% of the available meteorites are recoverable). If these assumptions are correct, North Dakota mines may be expected to recover up to 9 kg (19.8 pounds) of meteorites per year. In addition to the theoretical science behind the iron meteorite preservation, this number was also calculated based on the assumption that 99% of the available meteorite would be recovered.

The Penn State geologists are hoping that the large magnets, typically suspended over coal conveyor belts to prevent pieces of metal from getting into the boilers, will pick up pieces of iron meteorite from the coal. In North Dakota, coal and utility company personnel have been routinely checking these metal detectors but have not found any suspected meteorites (*Figure 13*). In addition to the large suspended magnets, metal detectors are also commonly used to keep metal out of coal-fired furnaces. When metal is detected an automatic cutoff switch is tripped and the conveyor belt shuts down until the metal is removed by hand. Some systems automatically dispense a shot of spray paint in the area where metal was detected to aid in its identification and removal. Commonly the magnets and metal detectors pick up pieces of cutting teeth that have broken off bulldozer buckets or teeth from the coal crusher. Blasting and mining of the coal may significantly reduce the size of any iron meteorites preserved in the coal. Therefore, these meteorites may be present but too small to be picked up at the magnet or detected by the metal detectors.

Figure 12. Flyer sent to local coal companies asking for their assistance in identifying iron meteorites in coal.

GENERAL METEORITE INFORMATION

Monetary Value of Meteorites

Meteorites and fossils share a similar fate, both are most often found by the hobbyist or discovered by landowners. Scientists rely on these finds to provide them with accurate information as to the location of the find, stratigraphic position, etc. In recent years, the prices offered for both fossils and meteorites on the open market have made it very difficult for universities and museums to compete for specimens. As a result, there is the danger in both fields of geology that scientists are not being afforded the opportunity to study important finds.

This is not an entirely new phenomenon. T.T. Quirke complained in 1918 that the collector who beat him to the Richardton meteorite drove the cost up on the remaining specimens. At that time, specimens of this meteorite were being purchased for upwards of $15 per pound. In 1938, State Geologist Howard Simpson stated that $1.00 per pound was considered a fair price for a meteorite. In 1968, State Geologist Wilson Laird noted that meteorites were selling at anywhere from a few dollars up to $40 per pound (Mandan Pioneer, August 21, 1968). Presently, meteorite dealers on the Internet are advertising meteorites for sale with prices generally ranging between 50 cents to $200 per gram ($227 to $90,700 per pound). One dealer (Michael Blood) noted that most of the low end meteorites

Figure 13. Dennis James (geologist at Falkirk Mine) stands next to a large magnet suspended over the coal conveyor at the Falkirk Mine. The magnet typically removes crushing teeth and parts of dozer blades which occasionally get mixed in with the coal during mining.

currently selling for $10.00/gram ($4,540 per pound) were selling for $2.00/gram ($908 per pound) only 10 years ago. Blood points out that most meteorites have increased in value 200 to 300 percent in the last few years which he attributes to the increase in collectors throughout the world. Some of these price increases may be attributed to the phenomenal interest in Mars meteorites following the August, 1996 announcement of suspected fossilized micro-organisms in these meteorites. These findings have recently been challenged by other scientists. In the meantime, Mars meteorites have sold at auction for up to $1,556 per gram (which works out to $700,000 per pound). More recently, a man in Champlin, Minnesota sold a 123 pound iron meteorite, that he dug up in his backyard while excavating for a sewer line, for $38,000 (roughly $300 per pound) (Minneapolis Star Tribune, January 14, 1998, pages 1 and 10A). For thirteen years the homeowner wondered what this unique rock was, first displaying it on his doorstep and later storing it in his garage before sending a sample of it to the University of Minnesota for analysis.

Why Aren't More Meteorites Found

Harvey Nininger (1952) estimated that about once every two thousand years every spot on the surface of Earth falls within an area of a meteorite shower. Based on this frequency of events, every square mile of Earth's surface should receive numerous meteorites over the course of a million years. Approximately 75% of North Dakota is covered by glacial deposits. As a result, the majority of meteorites that fell in the State over the last million years would likely have been incorporated into glacial sediment. In contrast, much of the southwest corner of the state has been subjected to weathering over the past several million years resulting in the removal of hundreds of feet of sediment from many areas.

A disproportionate amount of North Dakota's meteorites has been found in the Red River

Valley. This is likely because the area is covered by lake deposits, deposited by Glacial Lake Agassiz, that are relatively devoid of rocks. In other words, it is much easier to spot a meteorite in a plowed field that contains few, if any, other rocks. For this reason, and because the topographically flat lake clays are heavily farmed, the deposits of glaciolacustrine clay are the best areas in the State to search for meteorites (*Figures 14 and 15*).

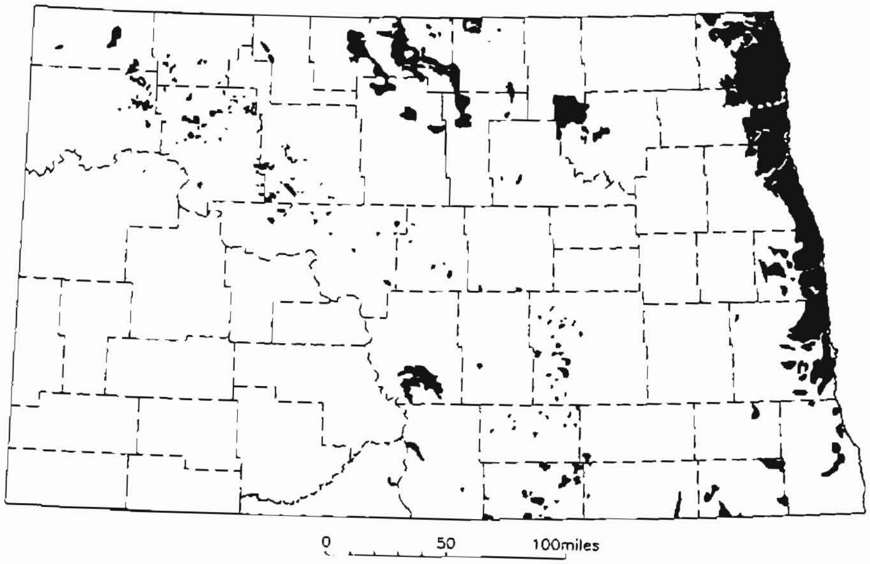


Figure 14. The locations of glaciolacustrine deposits (solid pattern) in North Dakota (modified from Clayton and others, 1980). The relative absence of rocks in the soils developed on these geologic units makes them very good areas to prospect for meteorites.

Figure 15. A rock-free plowed field situated on glaciolacustrine deposits near Bowesmont in Pembina County, North Dakota. This photo was taken a few miles southeast of the site where Sandy McDonald found specimens from two different meteorites on the same quarter section.

Meteorites would be much more common were it not for their susceptibility to weathering processes. Prior to encountering the surface of Earth, meteorites have been subjected to little or no free oxygen and moisture. In many cases it only takes a few years for the metal content of these meteorites to begin to oxidize. The fusion crust of stony meteorites often helps to protect the meteorite from weathering. However, even a small crack or chip in the fusion crust often accelerates the weathering process. For example, Harvey Nininger (1952) collected some stony meteorites twenty years or so after they fell that were so badly weathered that they crumbled in his hand.

The susceptibility of meteorites to weathering is why attention of scientists has turned to Antarctica over the last 20-25 years. The desert climate of this region helps to preserve the meteorites and they are much easier to find against a backdrop of ice. In addition, flowing glacial ice has concentrated these meteorites on the upstream side of mountains that protrude through the ice. The importance of Antarctica to meteorite hunting cannot be overstated. Over three-fourths of the world's known meteorite specimens (16,000 out of 20,000) have come from Antarctica, most of these within the last 25 years.

Identifying Meteorites

The North Dakota Geological Survey and the Department of Geology and Geological Engineering at the University of North Dakota get quite a few meteorite inquiries. Typically, a newspaper or magazine article on meteorites brings a few unusual rocks out of basements or sheds where they have languished for years. Often, these are rocks that were picked from a field or a rock pile years ago because they looked different than other rocks. A recent meteorite inquiry came from Earl Seilinger, a farmer northwest of Wing. Mr. Seilinger had long speculated that a large rock in his pasture was a meteorite because it was situated in the middle of a shallow depression and had smooth, shiny sides. Upon examination, it was determined that the object was a large block of granite transported from southern Canada tens of thousands of years ago by glaciers (*Figure 16*). This glacial erratic sits in a depression created primarily by the hoofs of bison as they rubbed against the rock over a period of thousands of years. The rubbing of the bison rounded and smoothed the edges of the rock giving it a vitreous (shiny) luster.

Over the years, Nels Forsman and Frank Karner have examined countless objects that were brought to them because they were thought to be meteorites (*Figures 17 and 18*). Although they have seen a wide variety of rocks and manmade objects, the majority of items have turned out to be lumps of iron slag from various furnaces and smelters. In addition to furnace slag, iron-bearing rocks (typically containing magnetite and hematite) may also be mistaken for meteorites. Furnace slag catches farmer's eyes when they see it in a field and it is reasonable to assume that it might be a meteorite given its general appearance (*Figures 17A and 18*). Scientists familiar with meteorites can generally tell at a glance whether a piece of metal is an iron meteorite or not based on its outward appearance. If they are uncertain, however, they can perform two tests on the object. The first requires a small piece be removed and analyzed for the presence of nickel. Nickel is generally absent in slag but almost always present in iron meteorites. The definitive test for an iron meteorite requires a face to be cut into the rock, polished, and etched in acid. The acid-etched face of an iron meteorite will almost always contain a series of grain outlines called the Widmanstatten pattern (*Figure 19*).

Figure 16. A large glacial erratic on the Earl Seilinger farm northwest of Wing in Burleigh County (T144N-R76W nwsw 27).

Figure 17. Examples of suspected meteorites picked up by North Dakota farmers. A. On the left: Dwayne Huus of Emrick (Wells County) holds a chunk of metal that he picked up years ago and thought might possibly be an iron meteorite. It was determined not to be a meteorite based on its external appearance which includes the presence of numerous vent holes. It is likely a piece of furnace slag. B. On the right: Wilburt (Bud) Smith, Burke County, holds a terrestrial rock which has an unusual weathering pattern which led Bud to believe might be part of the fusion crust.

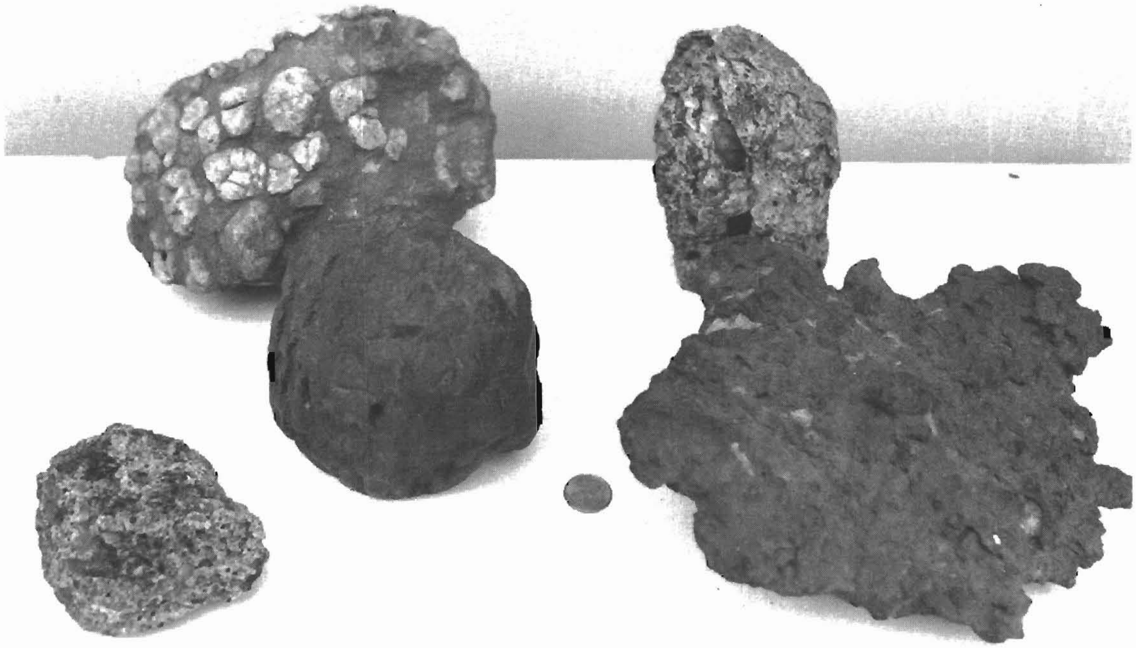


Figure 18. A few of the suspected meteorites that have been brought into the Geology Department at the University of North Dakota over the years. Back row (left to right): a piece of basalt porphyry; sediment fused by a burning haystack; front row (left to right): another piece of sediment fused by a burning haystack, ironstone, and a scrap piece of fused metal (metal slag) from a blacksmith or welding shop. Unlike these examples, meteorites do not look as if they were once molten, they do not bear deep pits or vesicles, and they do not look like aggregates of more than one rock (i.e., conglomerates or porphyries).

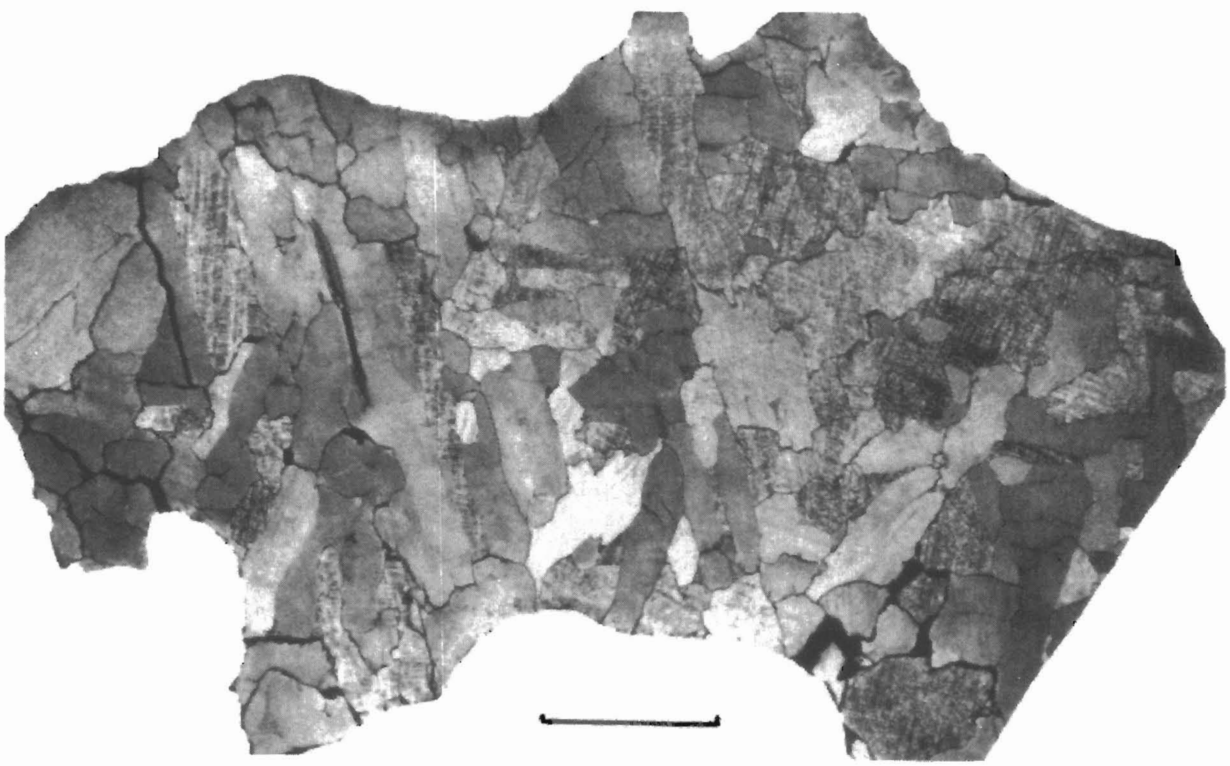


Figure 19. Widmanstatten pattern on an acid-etched, polished face of the New Leipzig meteorite. This pattern of iron mineral outlines is characteristic of iron meteorites. Scale bar is 15 mm. Photograph courtesy of the U.S. Natural History Museum (N.M.N.H. specimen no. 1210, S.I. negative no. 1658).

Table 2. Five Characteristics That Aid in Identifying Potential Meteorites.

1) Most meteorites contain at least some metal (typically an alloy of iron and nickel), even the stony meteorites, and therefore **will easily attract a magnet**.

2) Many meteorites have densities higher than that of the average terrestrial rock and will therefore **feel heavier than a typical rock**. This is especially true of the iron meteorites.

3) The most common stony meteorites or "chondrites" contain small round grains (chondrules) of stony material that are about a millimeter wide. The interior surfaces of stone meteorites have a very unique appearance. Unlike sandstones, which typically contain a mixture of similar sized grains, **stony meteorites contain very distinguishable large, rounded grains**.

4) As a meteorite falls through Earth's atmosphere a thin layer on the outer surface of the rock vaporizes. This thin layer **(fusion crust) is often black but will often turn brown (rust) on meteorites that have been on the surface of Earth for an extended period of time**. Meteorites typically break into numerous pieces as they fall and therefore an individual specimen may not necessarily bear a fusion crust.

5. Occasionally, the outer surface of a meteorite **may also become dimpled due to the heat of atmospheric passage**. These dimples, called regmaglypts, are similar in appearance to thumbprints in clay.

(Modified from Adrian Brearley, personal communication, 1998)

What To Do If You Think You Have Found A Meteorite

If you have a rock that meets some of these criteria you may want to bring it to the North Dakota Geological Survey office in Bismarck or to the Department of Geology and Geological Engineering at the University of North Dakota. Geologists at the University have access to analytical equipment which can aid in the identification of meteorites. Most geology or Earth science departments on college campuses in the State have individuals who should be able to properly identify meteorites. Additional places to send specimens for identification are the Department of Geology and Geophysics at the University of Minnesota, the American Meteorite Laboratory in Denver, the Center for Meteorite Studies at Arizona State University, or the National Museum of Natural History in Washington, D.C. In all cases, it is important to document as closely as possible where and under what circumstances the rock was collected.

REFERENCES

Buchwald, V.F., 1975, Handbook of iron meteorites: Berkeley, University of California Press, 1418 p.

Childress, J.O., 1996, Harvesting fossil meteorites: Geotimes, October, p. 14.

Clayton, Lee, Moran, S.R., Bluemle, J.P., and Carlson, C.G., 1980, Geologic map of North Dakota: United States Geological Survey.

Graham, A.L., Bevan, A.W.R., and Hutchison, R., 1985, Catalogue of meteorites, with special reference to those represented in the collection of the British Museum (Natural History): The University of Arizona Press, Tucson, p. 460

Henderson, E.P. and Perry, S.H., 1942, The Freda, N.Dak., meteorite: a nickel-rich ataxite: Proceedings of the United States National Museum, vol. 92, no. 3134, p. 21-23.

Huntington, O.W., 1890, A new meteoric iron from Stutsman County, North Dakota: Proceedings of the American Academy of Arts & Sciences, No. 25, pp. 229-232.

Huss, G.I., 1976, The Huss collection of meteorites of the American Meteorite Laboratory: American Meteorite Laboratory, Denver, Colorado, 58 p.

Karner, F.R., 1968, Meteorites in North Dakota: North Dakota Geological Survey Miscellaneous Series no. 37, 8 p.

Mason, Brian, 1962, Meteorites: John Wiley and Sons, Inc., New York, 274 p.

Moore, C.B., 1971, Meteorites: Earth Science Curriculum Project, Pamphlet Series PS-10, Houghton Mifflin Company, Boston, 46 p.

Morrison, David, 1992, The Spaceguard survey, report to the NASA International Near-Earth-Object Detection Workshop: NASA Ames Space Science Division, January 25.

Nininger, H.H., 1952, Out of the sky, an introduction to meteoritics: Dover Publications Inc., New York, 336 p.

Preston, H.L., 1902, Niagara meteorite: Journal of Geology, vol. 10, pp. 518-519.

Quirke, T.T., 1919, The Richardton meteorite: Journal of Geology vol.27, no.6, p. 431- 448.

Sears, D.W.G. and Dodd, R.T., 1988, Overview and classification of meteorites, in Meteorites and the early solar system: Kerridge, J.F. and Mathews, M.S. eds., University of Arizona Press, Tucson, p. 3-35.

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