Meteorites from the Pacific Northwest

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INTRODUCTION

One day, long before Europeans arrived in the Pacific Northwest, the fiery trail of a large meteorite illuminated the skies over southern Oregon. Unlike the distant shooting stars that can be seen on any clear night, the glow in the sky warned of an imminent arrival of a 1,167-kg (1.3-ton) mass of nickel-iron alloy that had once been part of the core of an asteroid. After more than 4 billion years in orbit, the eggshaped object hurtled into our atmosphere at a velocity of somewhere between 11 and 32 km per second. The meteorite's trajectory was toward the lava beds of southern Oregon and northern California, but the object's final resting place was a high mesa near Goose Lake in northern Modoc County, California, only a mile short of the Oregon border.

The meteorite was found on October 13, 1938, by three deer hunters and was recovered the following year by meteorite scientist H.H. Nininger, assisted by three professors from the University of California at Los Angeles, several local residents, and a team of boy scouts. The specimen was loaded onto a sturdy wagon and hauled by four draft horses over 2.5 mi (4 km) of muddy, boulder-strewn trail to reach the nearest road (Figure 1), ultimately headed for the exhibition halls of the National Museum in Washington, D.C. The Goose Lake meteorite is presently the largest meteorite in the Smithsonian's collection (Leonard, 1939).

Oregon's near-miss experience with the Goose Lake meteorite provides an appropriate background for this review of meteorites from the Pacific Northwest, because the state is better known by meteorite enthusi-

Figure 1. Goose Lake, California, meteorite loaded on cart for transport. From Nininger (1972), p. 177.

asts for tales of frustration rather than for happy discoveries. Examples include the Willamette meteorite, which triggered a bitter property-rights dispute that ultimately resulted in the removal of the nation's largest recovered meteorite to the east coast. The well-publicized story of the "lost" Port Orford meteorite has given several generations of Oregonians the hope of another spectacular find, but this legendary discovery now appears to have originated as a hoax (Clarke, 1993).

Disappointments continue to plague meteorite hunters: a spectacular fireball and smoke trail marked a meteorite arrival in Grant County on the afternoon of October 23, 1987. Witnesses described a "whomping" sound similar to the noise made by a helicopter, as well as an explosion that probably marked the meteorite's disintegration during its final passage through the atmosphere. The flight path was established by compass bearings made by a Forest Service archaeologist who happened to be working at a site in the Ochoco Mountains, and a logging crew at Pismire Camp on a ridge northwest of Mount Vernon happened to be almost directly beneath the object when it exploded at an altitude of 18,000 ft (5,500 m). This evidence allowed the impact site to be determined within a few miles. But the steep, forested terrain presents adverse conditions for meteorite hunting, which is made even more difficult by the abundance of black basaltic rocks that camouflage the presence of extraterrestrial arrivals. So far, the meteorite has not been found (Pugh and others, 1989; Norton, 1994). Fireballs are relatively common astronomical events, but meteorites are rarely recovered. Oregon fireballs have been described by Pugh (1982, 1984, 1987, 1993, 1995, 1997); Pugh and Stratton (1991); Pugh and McAfee (1993).

ORIGIN OF METEORITES

The vast majority of meteorites are fragments of asteroids, microplanets that orbit the sun within a series of well-defined belts that are located between Mars and Jupiter. Asteroids were once thought to be pieces of a single planet that broke apart billions of years ago, but the wide range of compositional variations observed in meteorites suggests that they derived from many different parent bodies (McSween, 1987).

Most asteroids travel in the same direction in which the planets in our solar system rotate but along paths that cause them to periodically approach the Earth. These orbital intersections may cause an asteroid to be captured by our planet's gravitational field. *Meteors* are bits of extraterrestrial matter that are accompanied by a blaze of light as they are heated by friction during their transit through the atmosphere. *Meteorites* are objects that actually strike the Earth's surface.

A few meteorites have been discovered that contain trapped gasses resembling the composition of the Martian atmosphere. This suggests that these objects originated as crustal rocks ejected from Mars by large meteorite impacts (Bartusiak, 1981; Vickery and Melosh, 1987). These specimens also show radiometric ages of only about 1.3 billion years, compared to the 4.5 billion years of meteorites derived from asteroids. Among the rarest of all are meteorites are fragments of the moon. Of the more than 10,000 meteorite specimens that have been recovered from Antarctica, eight appear to be of lunar origin.

DISTRIBUTION

Most asteroids travel in orbital planes that are approximately parallel to the Earth's equator. This causes impacts to be somewhat more abundant at middle latitudes than in the polar regions. Otherwise, meteorite impacts have a random distribution pattern, and they occur with surprising frequency. Perhaps 100 to 1,000 tons of extraterrestrial matter strikes our planet each day, mostly in the form of dust-sized particles (Dodd, 1986). Over the past 4.5 billion years, this volume is equivalent to a surface layer about 5 in. (12.7 cm) thick. Meteorites weighing 1 g (0.04 oz) or more arrive at an annual rate of about 8 per square mile, but only a tiny percentage of these are ever discovered. Several hundred meteorites weighing 1 ton or more strike the Earth each year, but most escape detection, partly because 72 percent of the planet is covered by water.

Geography plays an extremely important role in determining the success rate for meteorite recovery. Most meteorites are discovered in prairies, deserts, and other regions that contain few surface rocks. Antarctic glaciers have recently been discovered as particularly favorable collecting locations. Extensive ice sheets provide large areas where cosmic debris accumulates free of rocks. Ice that melts and evaporates in "ablation zones" causes meteorites to be concentrated in a relatively small area, where they are gathered by packs of scientists traveling on snow machines (Marvin and MacPherson, 1992).

Meteorites are susceptible to rapid oxidation, and the combined forces of weathering, erosion, and sedimentation cause most impact craters to be quickly obliterated. Without such geologic processes, the surface of our planet would resemble the Moon or Mercury, two locations where impact craters have been preserved for billions of years (Figure 2).

Meteorites that hit land are likely to be recovered only when they strike densely populated regions, particularly in nations where people have been educated in basic principles of geology and astronomy. This principle is well illustrated by the spectacularly successful efforts of Harvey Nininger, who abandoned his college teaching career to devote his life to searching for meteorites. Over a span of nearly 50 years, Nininger tirelessly spoke at schools, churches, taverns, and any other location

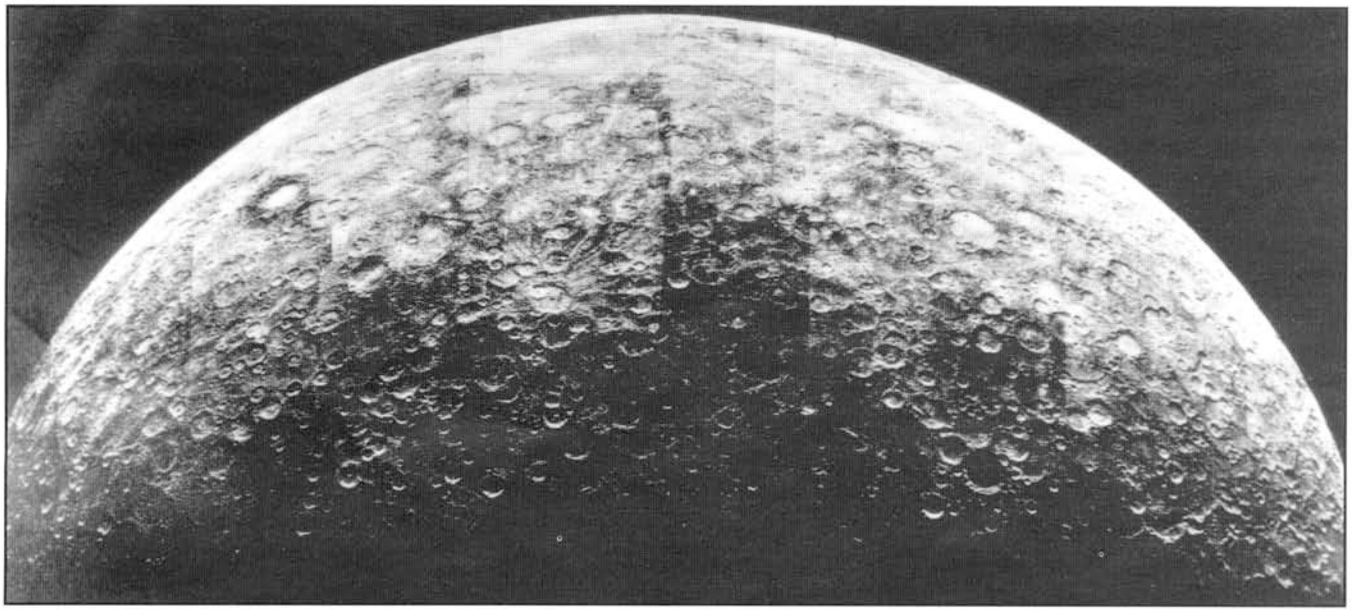


Figure 2. Meteorite impact craters on Mercury. From photos taken March 29, 1974, by the Mariner space probe. The largest craters are 200 km in diameter. Source: National Aeronautics and Space Administration.

where people gathered. Passing around a few specimens, the scientist asked his audience to contact him if they found any odd rocks. As a further reminder, he distributed as many as 200,000 leaflets. These efforts resulted in his acquisition of more than 2,000 meteorites, accompanied by a trove of new scientific information (Nininger, 1972).

On a much smaller scale, then Oregon State Geologist Hollis Dole, science writer Phil Brogan, and Portland State University professor Erwin Lange organized a publicity campaign to declare 1968 "The Year of the Meteorite," in the belief that more specimens might be found in Oregon if residents knew what to look for. This campaign failed to turn up any new meteorites, but the project resulted in the publication of a monograph that is still in print (Oregon Department of Geology and Mineral Industries, 1968). A similar plea by the Washington Division of Geology and Earth Resources produced no new specimens (Moen, 1973). In recent years, Portland science teacher Richard N. Pugh has been a leading investigator in the continuing search for meteorites from the Pacific Northwest.

Figure 3 shows the location of all known meteorite discoveries in the western United States. These data show the effect that geography and demographics have on the statistics of meteorite recovery. A multitude of meteorites probably remains undiscovered in the fields, forests, and deserts of the Pacific Northwest. Most discoveries have occurred in open, arid terrain, particularly in regions like eastern Colorado, where intensive agriculture causes the land to be inspected with great care. In addition, the presence of extensive loess deposits increases the likelihood that chunks of rock might be visitors from space. In contrast, Nevada and Utah both contain large desert areas where meteorites are likely to be preserved, but the scantness of population makes the odds of discovery very low, and the abundance of terrestrial rocks makes the recognition of meteorites difficult.

METEORITE RECOGNITION

Meteorites are seldom easy to recognize except in the rare cases where their arrival has been observed. Even alleged eye-witnessed impacts should not be taken for granted, and the literature contains many examples where nonmeteoritic specimens were collected from "observed" falls. These errors usually result from the failure of witnesses to realize that a meteorite's final impact site may be many miles distant from locations where the vapor trail was visible.

Meteorites can be divided into three main groups: irons, stones, and stony irons. Scientists further divide these categories into many additional subunits on the basis of data that can only be obtained by careful microscopic examination of thin sections (Mason, 1962; Wasson, 1974; Dodd, 1981; Sears, 1978).

As their name suggests, iron meteorites or "siderites" are composed mostly of interlocking crystals of nickel-iron alloy, often containing small inclusions of carbon and sulfur minerals. Iron meteorites are believed to originate within the inner core of asteroids, released when the parent bodies became fragmented during orbital collisions.

Such metallic meteorites are dark in color, strongly attracted to a magnet, and heavy for their size. The exterior surfaces rapidly alter to form a rusty rind. Unfortunately, these same

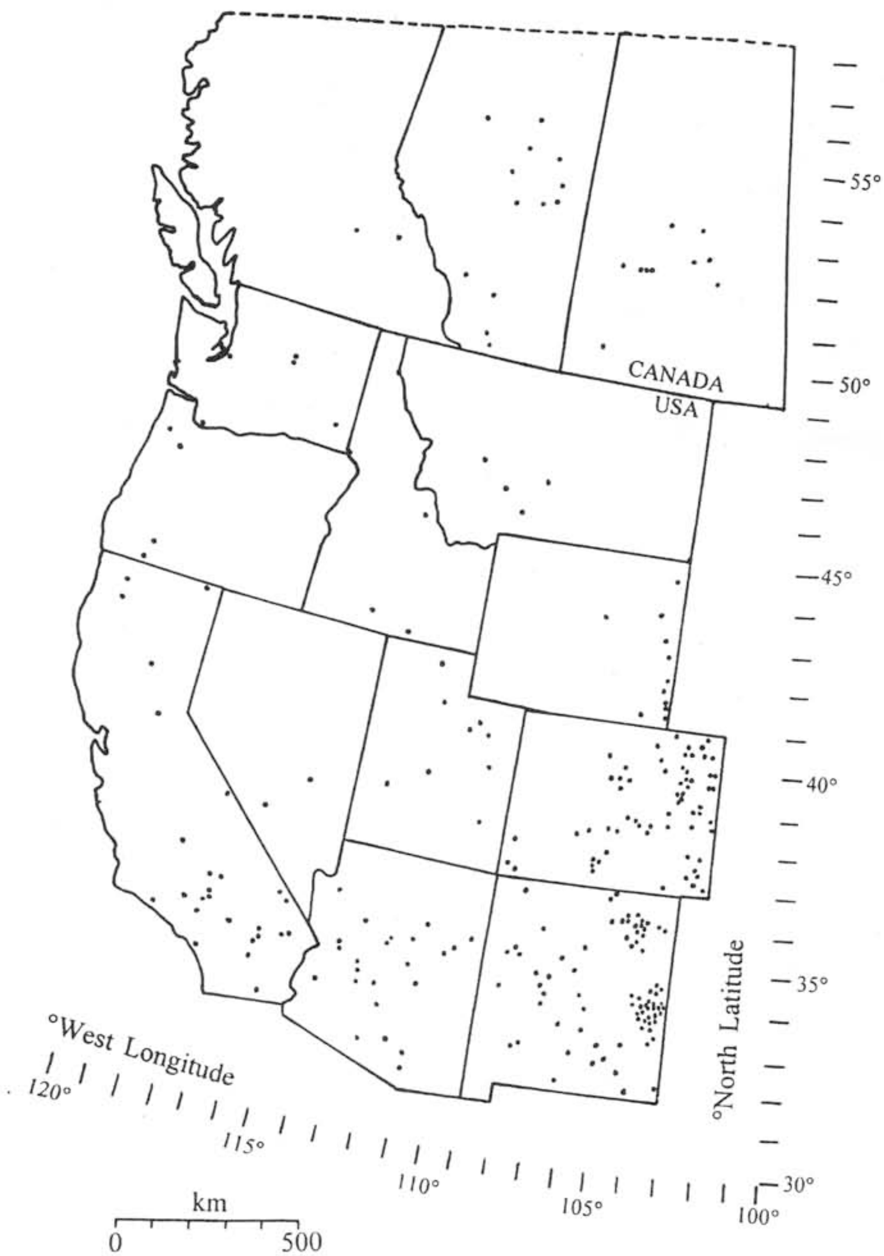


Figure 3. Known meteorite discoveries from the western United States. Data from Graham and others (1985).

characteristics are shared by slag, scrap metal, and some terrestrial iron ores. Metallic meteorites can most reliably be recognized by the presence of nickel, as revealed by chemical analysis. Etching sawn surfaces in dilute nitric acid sometimes reveals complex Widmanstätten patterns, which were created by crystals of kamacite and taenite, two types of nickel-iron alloy. Specimens from Sams Valley, Jackson County, Oregon, provide excellent examples of characteristics typically found in metallic meteorites (Figure 4).

Stony iron meteorites consist of approximately equal mixtures of nickel-iron alloy and crystalline silicates such as olivine and hypersthene. Pallasites are a variety that is particularly prized by collectors. They are composed of pea-sized crystals of olivine enclosed within a matrix of silver-colored metal. The only pallasite that has been reported from the Pacific Northwest is the meteorite fragment allegedly collected in 1856 near Port Orford, Oregon, a specimen now believed to actually have been found in Chile.

Stone meteorites are by far the most common variety to strike the Earth, although they are difficult to recognize because of their resemblance to terrestrial rocks. For example, a 26-kg (57-lb) rock was used as a door stop at Oklahoma's Beaver County jail for more than 40 years before it was identified as a meteorite. These asteroid fragments are primarily composed of mafic and ultramafic silicate minerals with small amounts of nickel-iron metal.

Stone meteorites are easy to identify only if they contain remnants of *fusion crust*, a glassy or sooty coating that forms from frictional heating (Figure 5). Otherwise, these meteorites may look much like various types of terrestrial rock, but magnetism remains a useful clue: Grains of nickel-iron alloy may not be visible to the naked eye, but stony meteorites are attracted to a magnet. Textures are commonly granular, resembling basalt or andesite, but some specimens show well-developed brecciation. Although some metallic meteorites contain rounded holes caused by weathering of inclusions, stony meteorites do not contain cavities, and nonmetallic rocks that show vesicular textures are almost certainly of terrestrial origin.

Careful examination of suspected meteorites by use of a hand lens (or better yet, a petrographic microscope) provides valuable evidence. Stony meteorites typically contain olivine, members of the pyroxene group (hypersthene, enstatite, and bronzite), and small amounts of plagioclase feldspar. Pyrite, mica, hornblende, and orthoclase feldspar do not occur in meteorites, and the presence of these minerals even in small amounts is clear evidence of the specimen's terrestrial origin. Quartz is exceedingly rare, and never present as a major constituent. Many stony meteorites contain *chondrules* (and are then called "chondrites")—tiny

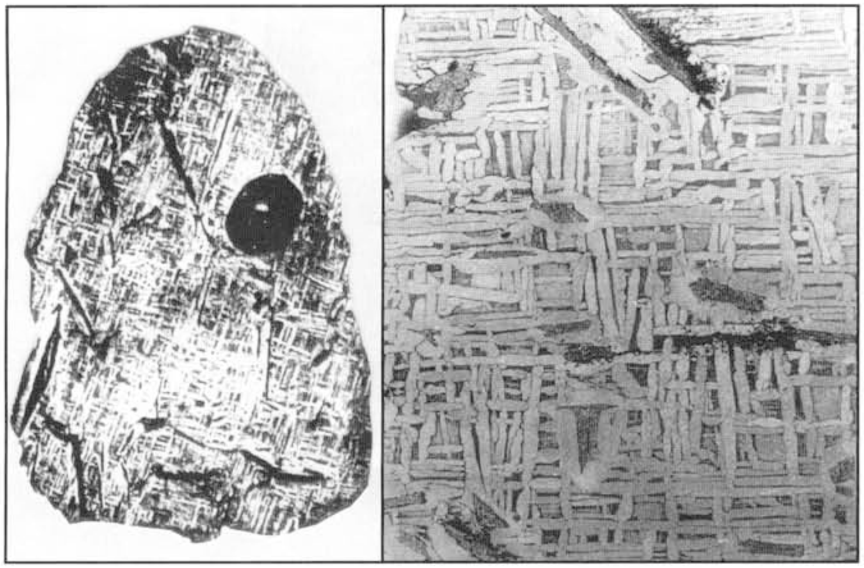


Figure 4. Widmanstätten pattern on etched slice of metallic meteorite from Sams Valley, Oregon. Actual size 12×17 cm. Right: Close-up of etched slab (magnification approximately 4X). Left picture from Foote (1915), right picture from Norton (1994).

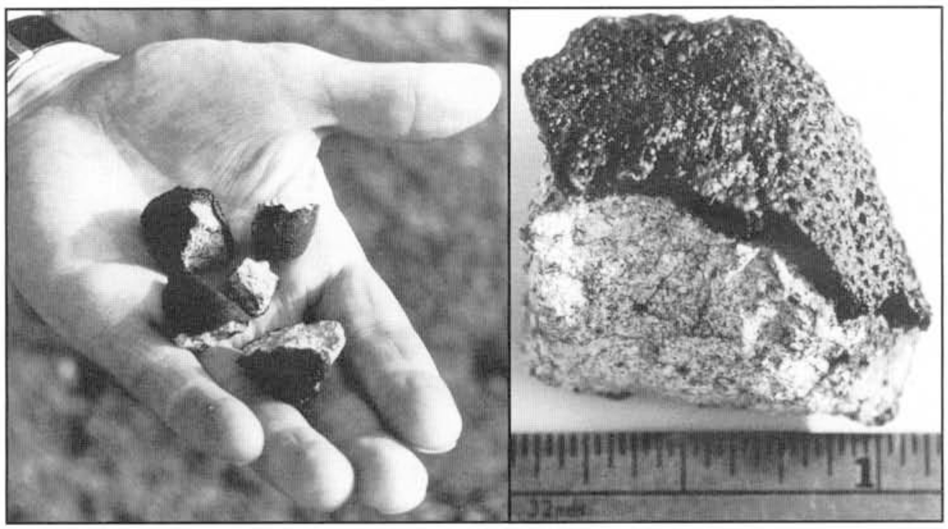


Figure 5. Fusion crust shown on the five recovered fragments of stony meteorite from Salem, Oregon (left), and in close-up view of one of the pieces (right). From Pugh (1983).

spherical grains that may be visible on broken surfaces or polished slabs. Metallic grains of nickel-iron alloy are almost always visible on polished surfaces as tiny silver specks dispersed within the silicate matrix.

Most geologists have little or no training in the recognition of meteorites, and identifications made by local universities or governmental agencies are not always reliable. Instead, meteorite identification is a task that should be left to experts. The appendix lists museums and universities that will identify specimens at no charge. In most cases, these institutions will offer to purchase samples that prove to be meteorites, but collectors need to keep in mind that meteorites legally belong to the person who owns the property on which they were found. Specimens found on state or federal land belong to the government, and legal ownership cannot be acquired by filing a mining claim, as meteorites are not considered to be a type of ore deposit. However, institutions such as the Smithsonian have sometimes been willing to pay finder's fees to people who report discovery of a meteorite on public land.

METEORITE OCCURRENCES IN OREGON

The following list includes alleged meteorite discoveries that have been described in publications ranging from scientific journals to local newspapers.

Willamette meteorite, Clackamas County, Oregon

The Northwest's most important meteorite discovery was made in the autumn of 1902 by Ellis Hughes, a 43-year-old emigrant from Wales. Hughes noticed an unusual rusty outcrop while he was cutting firewood near his farm just northwest of Willamette, a small community that has since been engulfed within the boundaries of West Linn, a Portland suburb. Previous experience as a prospector caused Hughes to believe that the rock was evidence of an ore deposit, and he notified his neighbor, William Dale. Dale pounded on the outcrop with a piece of stone, producing a metallic clang that led the

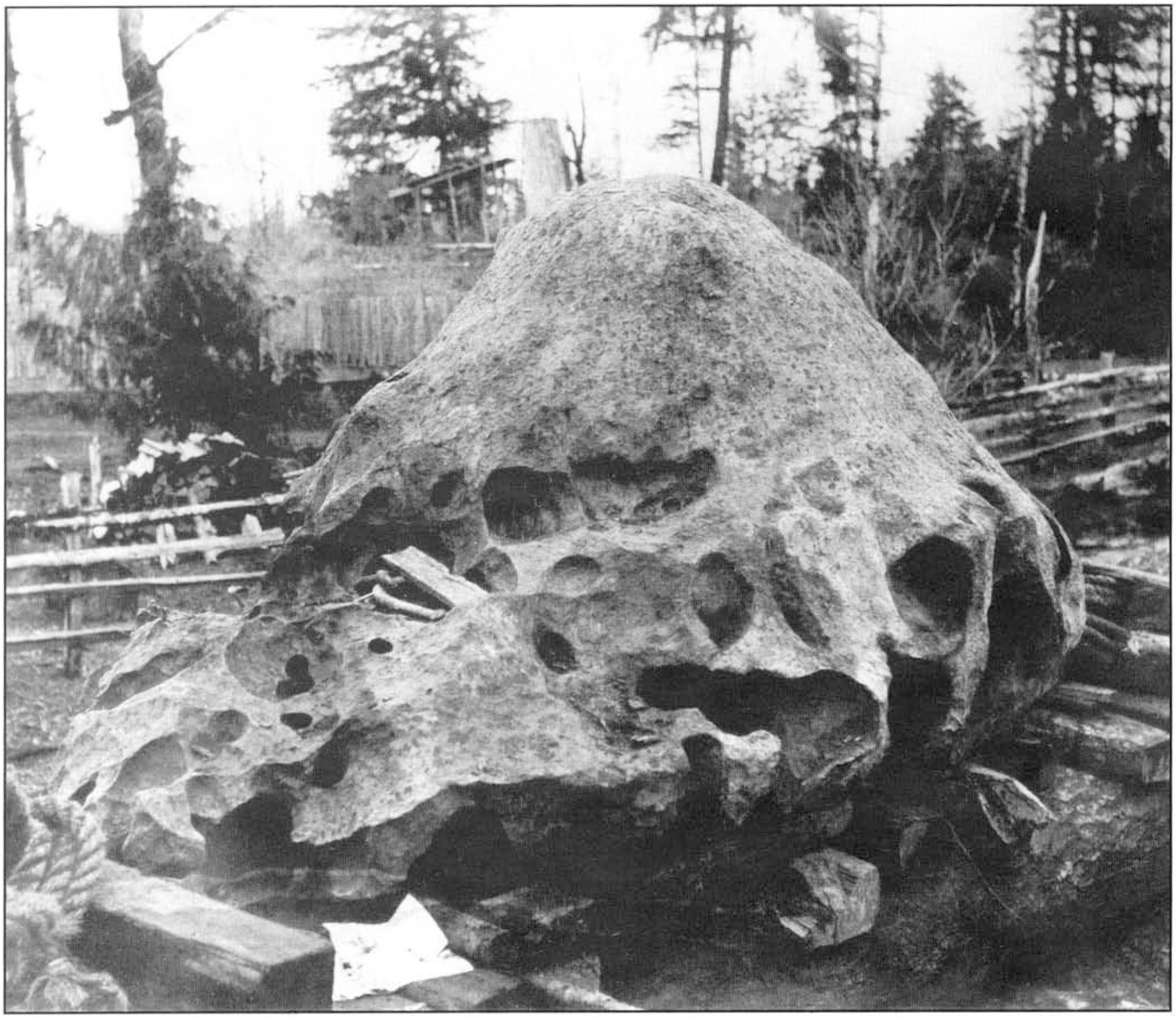


Figure 6. Willamette meteorite in front of the Johnson farm in the town of Willamette, on the southern outskirts of Portland, Oregon, at the time when it was being transported to its current location in New York. Photo by Harold Johnson from cover for Pugh and Allen (1986).

two men to conclude that they had discovered an enormous meteorite (Figure 6). Their excitement was dampened by the fact that the land was owned by the Oregon Iron and Steel Company, and they decided to hide the partially excavated meteorite under a layer of fir boughs, while they concocted a scheme to acquire ownership.

Dale traveled to eastern Oregon to sell a piece of property and thus raise money for purchasing the tract where the meteorite was located, but for reasons that are not clear he failed to return to Willamette. Lacking funds of his own, Hughes decided to transport the meteorite secretly to his farm. This ambitious task required moving the 15.5-ton (14,000-kg) mass three quarters of a mile through dense forest. Aided by his wife and their 15-year-old son, Hughes began excavating the meteorite in August 1902. During fall and winter, they cut a wagon road to the site, also constructing an additional stretch of road in the opposite direction as a distraction. By spring, they were ready to begin transporting the meteorite, using a massive wooden-wheeled cart attached to a hand-braided steel cable that was connected to a crude windlass. A single horse walked in circles around the capstan to provide the locomotion. Progress was tediously slow, on some days amounting to only a few feet; the best day's progress was only 150 ft (46 m). By summer's end, rain turned the path to a sea of mud, requiring construction of a plank road. After months of effort, the meteorite finally reached the Hughes family farmyard, and they attempted to profit from the enterprise by building a display shed and charging visitors 25 cents to view the largest meteorite ever found on United States soil. In North America, the Willamette meteorite is surpassed only by the 59-ton (54,000-kg) Ahnigito meteorite found at Cape York, West Greenland, in 1918.

The November 6, 1903, issue of the *Oregon City Enterprise* reported the rumor that the meteorite had been found on property adjoining the Hughes farm. On November 27, the Oregon Iron and Steel Company filed a suit demanding the return of the specimen after an unsuccessful attempt to purchase it for 50 dollars.

Hughes offered an innovative legal defense, claiming that the meteorite was an abandoned Indian relic that should be defined as personal property rather than land. Two elders from the Clackamas tribe testified that their ancestors had named the meteorite "Tomanawos" ("visitor from the Moon") and that it was considered a holy object that belonged to the Clackamas people. Earlier generations of warriors had dipped their arrows in rainwater that collected in cavities on the meteorite's surface to ensure success in battle, and young men were sent to the sacred stone to undergo secret initiation rites. This testimony is consistent with recent discoveries that Native Americans erected an adobe citadel around a 1.5-ton (14,000-kg) meteorite at Casas Grandes, Mexico (LeMaire, 1980). Other tribes may have made regular pilgrimages to meteorite sites at Red River, Texas, and Iron Creek, Canada (Nininger, 1952). Small meteorites have been found carefully wrapped and buried in Native American graves in Arizona and Montana (Lange, 1958b).

Hughes' lawyer expanded his arguments by pointing out the possibility that the meteorite had fallen at some other location and had been transported to the discovery site by glaciers, an argument that has been revived by scientists in recent years. The lawyer argued that the thorny property-rights issue could best be resolved by granting ownership of the meteorite to its discoverer, Ellis Hughes. Instead, the court awarded possession of the meteorite to Oregon Iron and Steel Company and assessed its value at $150. The decision was reaffirmed by the Oregon State Supreme Court on July 17, 1905, with the assessed value increased to $10,000.

The company announced that the Willamette meteorite would remain in Oregon forever, and it was displayed at the 1905 Lewis and Clark Exposition in Portland. When the exposition closed, a wealthy benefactor, Mrs. William E. Dodge, purchased the meteorite for $20,600 and donated it to the American Museum of Natural History in New York City. At that time, it was the highest price that had ever been paid for a specimen in the Museum's collection (Preston, 1988). In 1936, the Willamette meteorite was moved to the Museum's Hayden Planetarium, where it remains one of the most popular displays.

The Willamette meteorite has an asymmetric shape that indicates that the object maintained a constant orientation as it travelled through the atmosphere rather than tumbling randomly. The blunt side represents the leading face, and tapered bell-shaped sides formed as trailing surfaces. When it was initially discovered, the meteorite mysteriously rested in the soil in an upside down position. Prior to impact, the meteorite was possibly affected by air turbulence in the lower atmosphere. However, the immense mass of metal penetrated only about three feet into the soft forest soil, which suggests that the meteorite was not found at the original impact site. The meteorite may have been transported to its place of discovery by an iceberg during one of the great floods that swept across the Columbia basin during the late Ice Age. If so, the impact may have occurred in northern Idaho, western Montana, or southwestern Canada (Pugh and Allen, 1986). The story of this meteorite is also discussed in Lange (1958 a,b; 1962; 1968), LeMaire (1980), and Preston (1988).

Mulino meteorite, Clackamas County, Oregon

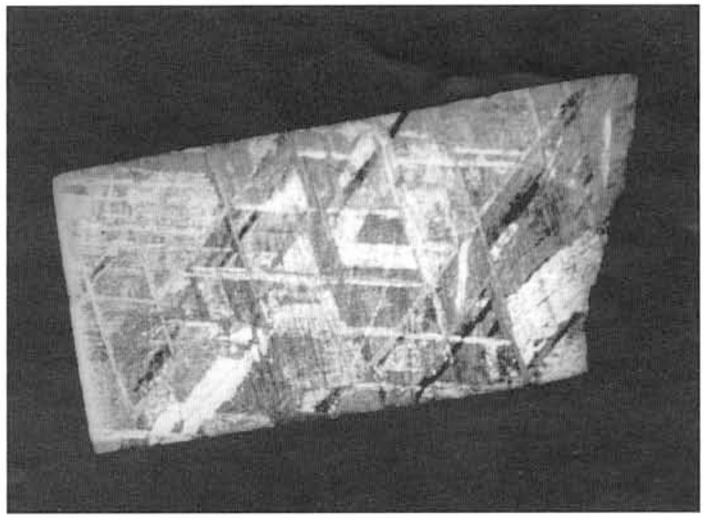
A very small chondrite in the U.S. National Museum is labeled as having fallen May 24, 1927, near Mulino. Later correspondence failed to reveal any local record of a meteorite fall on that date, and the authenticity of the specimen is ranked as "very doubtful" (Hay, 1966; Graham and others, 1985).

Sams Valley meteorite, Jackson County, Oregon

In 1894, a 6.8-kg (15-lb) metallic meteorite was found lying on rocky soil about 10 mi (16 km) northwest of Medford (Figure 7). The specimen was sold in 1914 to the Foote Mineral Company in Philadelphia, then one of the world's largest meteorite dealers. The meteorite was sawn into four main slices and several smaller remnants that were sold to museums and private collectors. A 1.1-kg (2.4-lb) specimen was purchased for $585 by the American Museum of Natural History in New York City, and a slightly smaller slice was purchased by Harvard University. Since then, four other Sams Valley specimens have been discovered, although the circumstances are poorly documented. In 1938, a 1.2-kg (2.6-lb) specimen acquired by the American Museum of Natural History from a Medford resident was forwarded to University of Oregon astronomer J.H. Pruett, who agreed to saw the specimen in exchange for a 1-lb portion. The actual cutting operation was performed by Eugene high school teacher C.A. Coulter and his teenage son Donald, an endeavor that took 11 hours and wore out 18 hack saw blades. Pruett's portion of the meteorite is now in the University of Oregon Museum of Natural History, along with a plaster cast of the

← Left: Figure 7. Two views of plaster cast of metallic meteorite found at Sams Valley, Oregon, in 1894. From Lange (1967).

↓ Below: Figure 8. Etched slice of Klamath Falls meteorite, showing Widmanstätten pattern. Photo courtesy O.R. Norton.



original 6.8-kg Sams Valley specimen. A 2-lb (1-kg) Sams Valley specimen on display at the Jacksonville Museum was discovered in 1949 among a box of uncurated minerals. This meteorite was one of three specimens that were found at Sams Creek in the 1880s by a local resident who was panning for gold. The other two pieces are presently unaccounted for. (See also Foote, 1915; Morley, 1950; Lange, 1967).

Klamath Falls meteorite, Klamath County, Oregon

In January, 1952, a resident in the area discovered a 17-kg (38-lb) metallic meteorite (Figure 8) somewhere in Klamath County. From examination of a small piece, meteorite expert H.H. Nininger confirmed that the sample was indeed a meteorite (Lange, 1968). The finder never returned to inquire about his discovery, and the location of his discovery site remains a mystery. The meteorite was acquired by the University of New Mexico and later subdivided. Small specimens have recently been sold to private collectors (Keith Kaler, Washington State Library, Olympia, oral communication, 1997). A 12.6-g (0.44-oz) sample is in the meteorite collection at the University of Arizona at Tempe.

Salem meteorite, Marion County, Oregon

At 1:05 a.m. PDT, on May 13, 1981, five small chondrite fragments struck the roof of the home of Deputy Sheriff James P. Price in Salem. At the time of the impact, Price was sitting on the curb talking to another deputy. Both men heard a peculiar "fluttering" noise that was followed by the sound of small rocks striking nearby. A search by flashlight produced a still-warm piece that had fallen within 10 ft of the officers. The next morning, four more fragments were recovered, consisting of angular gray stones with outer surfaces covered by a 1-mm-thick dark fusion crust (Figure 5). The specimens were sent to J.C. Evans, Senior Research Scientist at Battelle Pacific Northwest Laboratories in Richland, Washington, where they were analyzed by scanning electron microscopy and energy dispersive X-ray fluorescence analysis (Pugh, 1983). The specimens are now in the possession of Price. (See also Pugh, 1983; Clarke and Pugh, 1988).

South Slough meteorite, Coos County, Oregon

Dodge (1898, p. 442) recounts the tale of an alleged meteorite impact:

"One of the largest meteors on record fell on the head of South Slough, Coos County, January 17, 1890, at 11 o'clock at night, knocking a hole in the hill thirty feet across. It came from the northwest and lighted up the heavens in fine style. A report, as of thunder, awoke people for many miles around. It was plainly heard at Coquille City. Excavations reveal a chunk of lava twenty-two feet across that resembles slag from an iron furnace."

The reported size of the object far exceeds the 9'x9'x3' dimensions of the Hoba meteorite, the world's largest authenticated specimen, and a twenty-two foot meteorite would be unlikely to survive the thermal shock created during its passage through the atmosphere without being explosively fragmented. In the absence of additional information, the reliability of this historic report is very questionable.

Port Orford meteorite, Curry County, Oregon

A pallasite with an estimated weight of 10,000 kg (11 tons) was allegedly discovered in 1856 on a hillside about 40 mi east of Port Orford by John Evans, leader of a government-sponsored expedition to explore possible routes for the railroad. A 30-g (1.1 oz)specimen was turned over to the Boston Natural History Society. Several hundred parties have unsuccessfully attempted to locate this meteorite site in the Siskiyou National Forest in southwestern Oregon, beginning shortly after the discovery was publicly reported in 1859. The Smithsonian Institution organized searches in 1929 and 1939, and although these expeditions were unsuccessful, three articles written by University of Oregon astronomy professor J.H. Pruett triggered an avalanche of interest in the "lost meteorite" (Pruett, 1937, 1939a, 1950). For decades, professional and amateur treasure seekers have trudged the hills bordering the headwaters of the Sixes River looking for the "bald mountain" described by Evans as the site of the meteorite. Possible geographic clues have been described in detail by Henderson and Dole (1964).

Over the years, Evans' account of his discovery has continued to be the subject of considerable scrutiny, and the specimen he collected has been rigorously analyzed. A recent compilation of this information indicates that Evans made up the meteorite story as a hoax that was intended to attract funding for a future expedition and to generate money the geologist needed badly to repay the considerable personal debt that he had amassed from overspending his budget during the original trip.

The texture and composition of Evans' specimen are nearly identical to the Imilac meteorite discovered in the Atacama desert of Chile in 1822, and its weathered surface seems more likely to have been produced in the arid environment of the Atacama region rather than in the humid coastal forests of Oregon. This evidence suggests that Evans might have acquired a fragment of the Imilac pallasite when he passed through the isthmus of Panama on his return from Oregon, hoping that the specimen could provide the means of allaying his pending financial troubles. At present, a 24-g (0.8 oz) "Port Orford" specimen is in the Smithsonian collection (Figure 9), and small fragments are located at the Vienna Natural History Museum and the India Geological Survey Museum, Calcutta. (See also Buchwald and Clark, 1993; Plotkin, 1993; Sedell, 1968).

OTHER NORTHWEST METEORITES

All of the meteorites that have so far been discovered in Oregon have come from the region west of the Cascade Range, even though the less vegetated terrain in the central and eastern parts of the state offer more favorable conditions for meteorite recovery. This discrepancy is explained by the low population density east of the Cascades. In Washington, the most important meteorite specimens were found in the wheat fields of the Columbia Plateau, where extensive cultivation increases the chances that unusual rocks will be noticed.

Waterville meteorite, Douglas County, Washington

The first meteorite to be found in Washington was a 37-kg (82-lb) nickel-iron specimen discovered in 1917 on the Fred Fachnie farm, 16 mi northeast of Waterville (Figure 10). Fachnie's combine struck the Waterville meteorite with such force that the machine's bull wheel was broken. No obstacles had been encountered when the same field had been planted in the spring—with equipment that drilled holes at a 6-in. spacing. The farmer took the specimen to William Schluenz, owner of the local hardware store. Schluenz recognized it as a meteorite, and for the next few years the rock was dis-

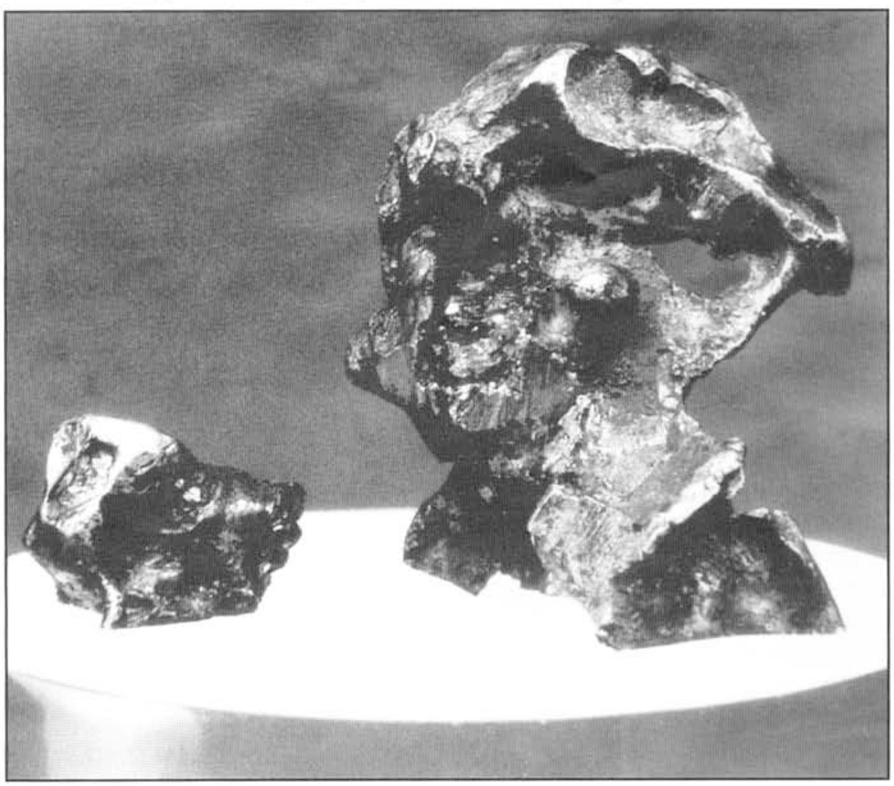


Figure 9. Fragments of meteorite allegedly found in 1856 near Port Orford, Oregon. The larger specimen weighs only 24 g. Photo by Chip Clark from Clarke (1993).

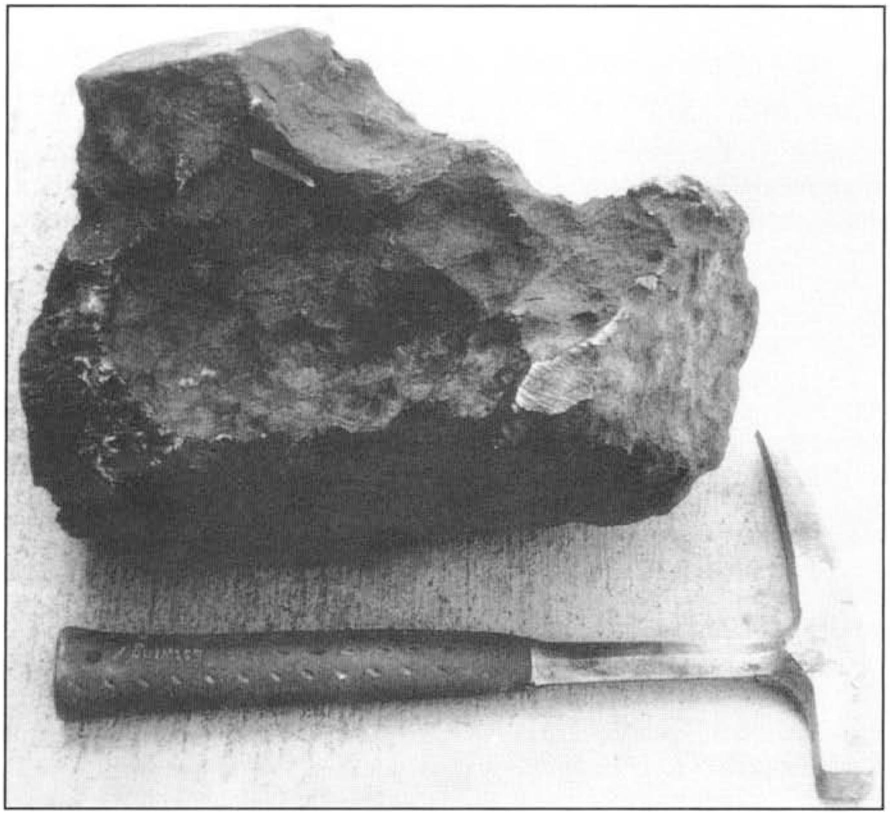


Figure 10. The 37-kg metallic meteorite from Waterville, Washington. From Knoblach (1994).

played in his store. Customers were permitted to try their hand at breaking the dense metallic mass with a hammer, and the meteorite's surfaces bear the scars of many unsuccessful attempts.

In 1921, Fachnie retrieved the somewhat battered specimen and used it as a decoration in his flower garden. In March 1925, a member of the Washington State Historical Society borrowed the meteorite for display at the Ferry Museum in Tacoma. In 1958, Wenatchee residents Mr. and Mrs. Walter Grizzle became disturbed by the museum's careless treatment of the specimen. Slices had been sawn from several of the surfaces, so that the original weight was reduced by nearly 4 kg (9 lb). The Grizzles instigated a four-year legal campaign to have the meteorite returned to the Fachnie family. The museum was unable to produce evidence that the specimen had been received as a donation rather than a temporary loan. In 1963, the meteorite was placed on permanent display at the Douglas County Historical Society Museum in Waterville. A large etched slice is in the Nininger collection at Arizona State University. (See also Read and others, 1967; Grizzle, 1963; Grizzle and Eller, 1961; Weinke and others, 1979).

Withrow meteorite, Douglas County, Washington

In the spring of 1950, an 8.75-kg (19.25-lb) metallic mass was found 1 mi west of Withrow in a wheat field owned by W.C. Nollmeyer, (Figure 11). Since 1966, the specimen has been on display at the Douglas County Historical Society Museum in Waterville. Another 5-kg (11-lb) meteorite found sometime prior to 1951 by a Withrow school teacher is presently unaccounted for. The Waterville and Withrow specimens are similar in composition and appearance, and they may have originated as part of a single shower (Read and others, 1967).

Albion meteorite, Whitman County, Washington

A 12.28-kg (27-lb) specimen found in the winter of 1966–1967 by Kenneth Oliphant in a wheat field adjacent to the Palouse River near Albion was confirmed to be an iron meteorite in 1991 by John Wasson, professor at the University of California at Los Angeles. The Albion meteorite is noteworthy because of the presence of irregular vacuoles that range in diameter from 4 to 9 mm (0.16–0.35 in.). These small cavities are lined with spherical masses that are covered with intergrown cubic crystals of almost pure iron, a feature never before observed in a meteorite (Kempton, 1995).

Washougal meteorite, Cowlitz County, Washington

On the morning of July 2, 1939, climbers on Mount Adams observed the glowing trail of a meteorite streaking across the western sky. Residents of the Portland area heard the accompanying sonic boom, and at 7:35 a.m. PST, a 225-g (8-oz) stony meteorite struck the ground near a person who was picking raspberries near the Columbia River town of Washougal, Washington. This arrival probably involved a mass that fragmented into many pieces just before impact, but searches failed to yield other specimens. The main body of the meteorite is at the University of Oregon Museum of Natural History (Figure 12), while small portions are in collections at Arizona State University and the British Museum. (See also Graham and others, 1985; Carver and Anders, 1975; Jerome and Michel-Levy, 1972; Nininger, 1939; Pruett, 1939b).

Tacoma meteorite, Pierce County, Washington

A single 16.7-g (0.6-oz) nickel-iron meteorite was found on a farm near Tacoma in 1925. Today, 12.1 g (0.4 oz) of it are left at the University of California, Los Angeles, and 2.2 g (0.08 oz) in the Smithsonian Institution. (Graham and others, 1985).

Colton meteorite, Whitman County, Washington

A highly oxidized metallic meteorite fragment was found a few years ago in the Palouse region of southeastern Washington. The specimen, which is presently at the Smithsonian Institution, has not yet been formally described (R.N. Pugh, oral communication, 1997).

Roy meteorite impact, Pierce County, Washington

On August 2, 1929, the *Tacoma News Tribune* reported the following story: "After a thorough investigation of the meteorite landing place on the farm of John L. Murray, two miles south of Roy, less than two weeks ago, it was discovered that the only trace of it left was a hole in the ground three feet in diameter and three feet deep, lined with grayish ash. This investigation led to the belief that in spite of the explosion, which broke windows and tore a door from its hinges on the Murray farm, the phenomenon was so hot as to be of a gaseous nature, when it reached the earth, disintegrating upon landing."

Small meteorites typically produce indentations that are only slightly larger than their own diameter, and failure to discover an object at the impact site is perplexing. Many incoming bodies undergo explosive disintegration as they make their final passage through the atmosphere, but the absence of fragments suggests that the Roy "impact" was possibly a lightning strike. As with many other anecdotal accounts of alleged meteorite impacts, the true story of this event may never be known.

Kirkland hoax (?), King County, Washington

Two small metallic objects pierced the dome of an amateur observatory just northeast of Kirkland at approximately 11 a.m. PST, January 17, 1955. The story began when Luther Hawthorne called the local fire department to report smoke issuing from his observatory, shortly after he had heard an explosive report. He discovered that the smoke was coming from a fire in a small shelf of reference books inside the building, and that two small holes were visible in one of the aluminum panels that formed the dome-shaped roof. He discovered two small metallic objects near the book shelf. The specimens proved to be metallic meteorites of somewhat different composition. Read (1963) provided a detailed discussion of this alleged fall, concluding that the event was a legitimate meteorite arrival. The implausible odds of a cosmic impact occurring at a back yard observatory causes most scientists to question the validity of this alleged meteorite arrival. Editions 3 and 4 of the *Catalogue of Meteorites* (Hay, 1966; Graham and others, 1985), a compendium of all known meteorite discoveries, rank the Kirkland fall as "very doubtful." The Kirkland specimens and the damaged dome panel were acquired by the Wenatchee meteorite enthusiasts

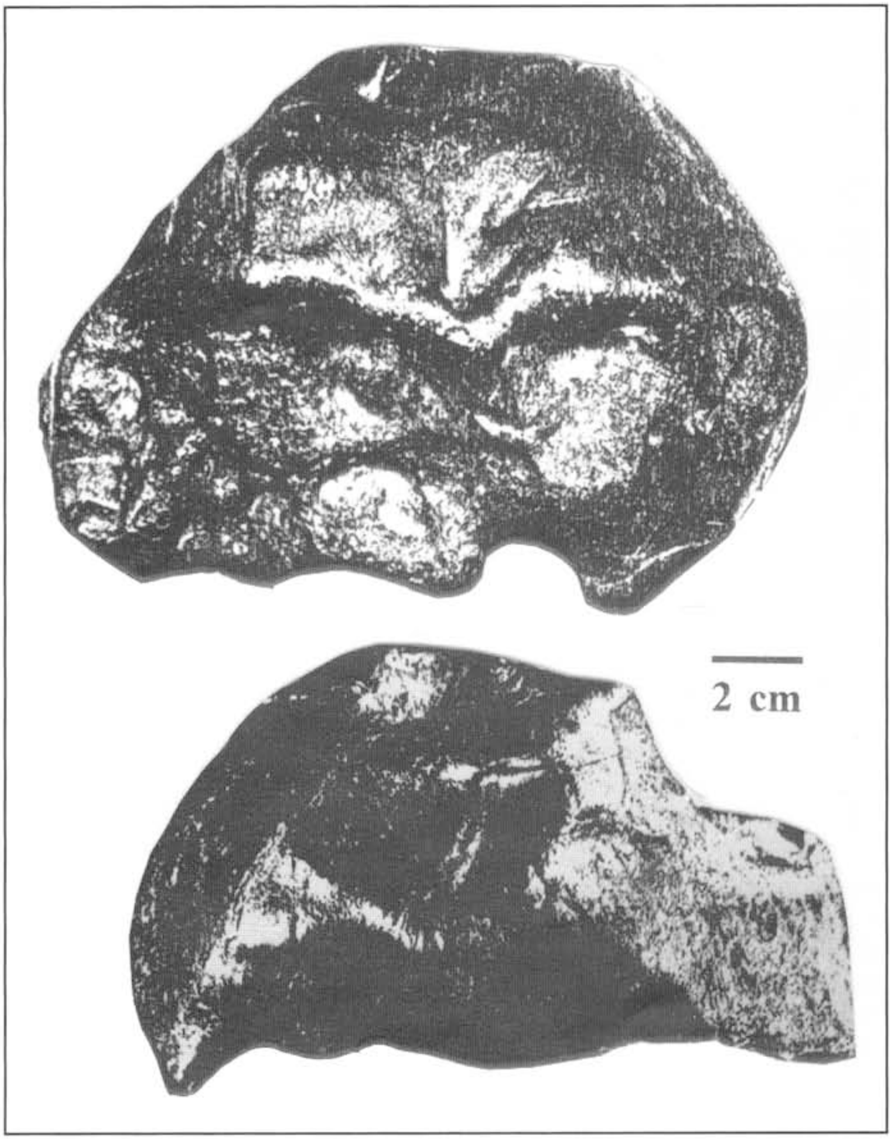


Figure 11. Two views of the 8.75-kg metallic meteorite found in 1950 at Withrow, Washington. Photos courtesy Douglas County Historical Society Museum, Waterville, Washington, which has the Withrow meteorite on display.

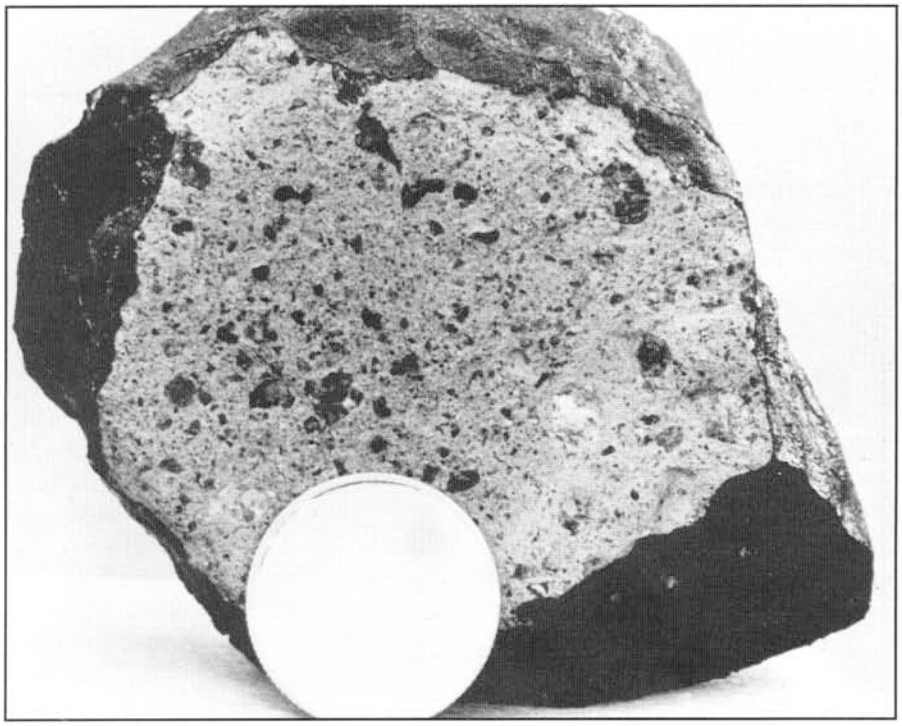


Figure 12. The 220-g stony meteorite that fell near Washougal, Washington, on July 2, 1939. Coin at bottom for scale is a dime (1.7 cm diameter). From Pugh (1982).

Walter and Ellen Grizzle and displayed in 1963 at the Douglas County Historical Society Museum in Waterville, Washington. The present whereabouts of the meteorites, however, are unknown.

Revelstoke meteorite, British Columbia, Canada.

The province of British Columbia ranks as one of the world's worst places to search for meteorites because of the rugged terrain, dense forests, and low population density. However, on the clear night of March 31, 1965, the spectacular arrival of a meteorite was witnessed by thousands of people in British Columbia and Alberta. An extraterrestrial object exploded high in the atmosphere somewhere above the peaks of the Monashee Range, producing shock waves that were detected by seismographs as far away as Colorado. These vibrations were evidence of a blast that had an estimated energy of 20 kilotons of TNT, approximately equal to the atomic bomb that destroyed Nagasaki in 1945 (Chyba, 1993; Carr, 1970, Folinsbee and others, 1967). The Canadian event caused no ground-level damage, however, and an extensive search failed to discover an impact crater. The only physical evidence consisted of millimeter-size meteorite fragments that two fur trappers found darkening the snow near Shushap Lake. Analysis of less than 1 g (0.04 oz) of recovered material revealed that the Revelstoke meteorite was a carbonaceous chondrite, one of the rarest types. As their name suggests, these meteorites contain significant amounts of carbon. Their overall chemical composition resembles the chemistry of the sun, and carbonaceous chondrites may provide us with samples of matter that existed during the earliest stages in the evolution of our solar system.

Beaver Creek, British Columbia, Canada.

Prior to the Revelstoke arrival, the only known meteorites from British Columbia were a pair of stones weighing 2.3 kg (5 lb) and 11.4 kg (25 lb) that struck Beaver Creek in the West Kootenay District on May 26, 1893 (Lange, 1973; Graham and others, 1985). These specimens were cut into slices that were dispersed among many collectors. The largest remnants are a 3-kg (6.6-lb) piece owned by the American Museum of Natural History in New York and a 2-kg specimen in the Field Museum of Natural History in Chicago.

All Pacific Northwest meteorites recovered to date came from relatively small impacts, but some think that the Pacific Northwest has also been the scene of very large cosmic events. Alt and Hyndman (1995) have suggested that an asteroid impact about 17 million years ago during the Miocene Epoch might actually have weakened the crust and triggered outpourings of basaltic lava over the Columbia Plateau and adjacent regions of Washington, Idaho, Oregon, and Nevada. Most geologists believe that conventional plate tectonic forces were responsible for this volcanism, but our increasing knowledge of numerous asteroids that travel in Earth-crossing orbits can suggest that some "extraterrestrial visitors" might play important roles in the geologic evolution of our planet.

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Helen Grande, Douglas County Historical Society Museum curator, provided historical information about the discoveries of the Waterville and Withrow meteorites. Dick Pugh and Beverly Vogt contributed helpful reviews of the manuscript.

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APPENDIX

Resource addresses for meteorite identification

Center for Meteorite Studies, Arizona State University, Tempe, AZ 85281.

Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131.

Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560.

The American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024.

Institute of Geophysics and Planetary Sciences, University of California, Los Angeles, CA 90024.

Lunar and Planetary Laboratory, Space Sciences Building, University of Arizona, Tucson, AZ 85721. □