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Ernst Florens Friedrich Chladni (1756–1827) and the origins of modern meteorite research

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Abstract–In 1794, Ernst F. F. Chladni published a 63-page book, *Über den Ursprung der von Pallas gefundenen und anderer ihr änlicher Eisenmassen und über einige damit in Verbindung stehende Naturerscheinungen,* in which he proposed that meteor-stones and iron masses enter the atmosphere from cosmic space and form fireballs as they plunge to Earth. These ideas violated two strongly held contemporary beliefs: 1) fragments of rock and metal do not fall from the sky, and 2) no small bodies exist in space beyond the Moon. From the beginning, Chladni was severely criticized for basing his hypotheses on historical eyewitness reports of falls, which others regarded as folk tales, and for taking gross liberties with the laws of physics. Ten years later, the study of fallen stones and irons was established as a valid field of investigation. Today, some scholars credit Chladni with founding meteoritics as a science; others regard his contributions as scarcely worthy of mention. Writings by his contemporaries suggest that Chladni's book alone would not have led to changes of prevailing theories; thus, he narrowly escaped the fate of those scientists who propose valid hypotheses prematurely. However, between 1794 and 1798, four falls of stones were witnessed and widely publicized. There followed a series of epoch-making analyses of fallen stones and "native irons" by the chemist Edward C. Howard and the mineralogist Jacques-Louis de Bournon. They showed that all the stones were much alike in texture and composition but significantly different from the Earth's known crustal rocks. Of primary importance was Howard's discovery of nickel in the irons and the metal grains of the stones. This linked the two as belonging to the same natural phenomenon. These chemical results, published in February 1802, persuaded some of the leading scientists in England, France, and Germany that bodies do fall from the sky. Within a few months, chemists in France reported similar results and a new field of study was inaugurated internationally, although opposition lingered on until April 1803, when nearly 3,000 stones fell at L'Aigle in Normandy and transformed the last skeptics into believers. Chladni immediately received full credit for his hypothesis of falls, but decades passed before his linking of falling bodies with fireballs received general acceptance. His hypothesis of their origin in cosmic space met with strong resistance from those who argued that stones formed within the Earth's atmosphere or were ejected by lunar volcanoes. After 1860, when both of these hypotheses were abandoned, there followed a century of debate between proponents of an interstellar versus a planetary origin. Not until the 1950s did conclusive evidence of their elliptical orbits establish meteorite parent bodies as members of the solar system. Thus, nearly 200 years passed before the questions of origin that Chladni raised finally were resolved.

IRONMASSES, APRIL 1794

At Easter time in April of 1794, a book by Ernst F. F. Chladni (Fig. 1) was published simultaneously in two cities: Leipzig, to reach physicists and astronomers in Germany, and Riga, to reach a German-reading public in northern Europe. The book, *On the Origin of the Mass of Iron found by Pallas and of other similar Ironmasses, and on a Few Natural Phenomena Connected Therewith,* commonly is called *Ironmasses* (Fig. 2). By featuring in his title a large mass of iron described by Pallas, Chladni sought to capture some of the widespread interest aroused by the book of travels in Siberia published in 1776 by the celebrated German natural historian Peter Simon Pallas (1741–1811). The "Few Natural Phenomena" of the title were fireballs and fallen stones and irons.

Fig. 1. Ernst Florenz Friedrich Chladni. (Reproduced by courtesy of Deutschen Staatsbibliothek, Berlin.)

From boyhood, Chladni, born in Wittenberg on November 30, 1756, held strong interests in mathematics, physics, music, and natural history. However, at the insistence of his father, a professor and Dean of Jurisprudence at the University in Wittenberg, he studied law and philosophy. In 1781 he passed his doctoral examinations in law at Leipzig, and in 1782 he earned a doctorate in philosophy at Wittenberg. Later that year, his father died, leaving him no fortune other than the precious freedom to pursue his own interests. Chladni stayed on at Wittenberg to continue his studies of mathematics and physics and to search for a university appointment. Failing that, he made his home in Wittenberg and returned there from all his travels. Chladni never married.

In 1785, Chladni read a paper by Georg Christoph Lichtenberg, professor of physics at the University at Göttingen, who described the dust patterns he produced on the resin plate of a charged electrophorus. Captivated by this observation, Chladni began experiments of his own on patterns produced in loose sand on glass or copper plates by vibrating sound waves. Within two years, Chladni (1787) earned his first measure of fame with *Entdeckungen über die Theorie des Klanges*, a book on the theory of sound waves. His continuing studies on that subject along with his inventions of musical instruments led to Chladni being called the "Father of Acoustics."

In 1790, Chladni outfitted a carriage to transport his first instrument, the euphonium, which he had invented and built in 1789–1790, to cities of Europe where he gave talks and demonstrations on sound waves and played at concerts. In early 1793, he visited Göttingen where he had the opportunity to meet and talk with Lichtenberg. Aged and crippled by that time, Georg Christoph Lichtenberg (1744–1799) ranked among the foremost physicists and natural philosophers of Europe. In his later writings (e.g., 1803:323; 1809:ix; 1819: 4), Chladni recalled that Lichtenberg had inspired him to undertake both of the principal research topics of his career: the physics of acoustics, and the physics of fireballs and meteorites.

With respect to meteorites, Chladni (1803:323) wrote:

> The initial idea for my book on such masses I had from Lichtenberg, whose outstanding talent truly was to throw out a few thoughts that gave new insights and could lead to further investigations . . . In our conversation in Göttingen in February, 1793 he told me that if all circumstances about fireballs were considered they could best be thought of not as atmospheric but as cosmic phenomena, that is to say that they are something foreign that arrive as bodies which came from outside of our atmosphere . . . he suggested that I search the *Philosophical Transactions* and other sources for reports of fireballs for which good trajectories had been recorded, and, for comparison, to search for reports of fallen masses.

Astounded by Lichtenberg's suggestion of possible cosmic sources for "igneous meteors," Chladni wrote that he spent three weeks in the library at Göttingen where he compiled historical reports of 24 well-documented fireballs and 18 witnessed falls of masses of stone and iron. Chladni found that the descriptions were so astonishingly similar from place to place and century to century that, to his lawyer's ear, the eyewitnesses were telling the truth: falling masses of iron and stone are genuine natural phenomena and not the fantasies of unlettered observers. He then linked the masses with fireballs, arguing that the falling bodies become incandescent as they plunge through the Earth's atmosphere. Finally, in order to explain the exceedingly high apparent velocities of fireballs, and the fact that fireballs and shooting stars appear from every direction in the sky, he adopted Lichtenberg's radical hypothesis that the masses originate in cosmic space. In just over a year of research and writing, Chladni completed his book on iron masses, which was the first one in early modern times to discuss meteorites as authentic natural phenomena.

With the physicists and astronomers of his time, Chladni shared mistaken ideas about the huge sizes of fireballs. He erred in supposing that high-altitude shooting stars, which light up only briefly, trace the passage of very small bodies through the upper atmosphere and out again into space, and he also erred in postulating that certain low-altitude meteors consist of spongy materials that rise from the Earth and catch fire. Nevertheless, every pioneer of a new field is allowed a few errors, and ultimately Chladni proved to have been so right so early about his principal hypotheses that today many meteoriticists share the view expressed by Wolfgang Czegka (1993:376): "Chladni founded meteoritics as a science by this paper."

Others, more cautious, credit Chladni with laying the groundwork for meteoritics,[1] but question whether any one person founds a new science. A warning against such claims was issued in 1982 by Reijer Hooykaas (1906–1994), the distinguished historian of science in the Netherlands. He argued that too many authors develop a tendency to hero-worship and then exaggerate the intellectual virtues of their heroes and overlook the merits of earlier and contemporary scholars. Hooykaas (1981–1982:22) wrote:

> Like most saints, those of the Church Scientific seem to perform miracles and, in some cases, they give birth to a new science, which before they appeared on the scene, existed at best in an embryonic state.

As one example, Hooykaas cited a remark by René Marcard (1938:21) who wrote, with a whiff of nationalistic pride, that chemistry, like Minerva of old, sprang fully grown from the head of a most eminent French savant named Lavoisier.

We know better about chemistry. The roots of modern chemistry were established well before 1789 when Antoine-Laurent de Lavoisier (1743–1794) issued his *Traité Élémentaire de Chimie*, in which he enunciated the principle of conservation of mass and provided a wealth of new insights on chemical reactions and combinations. Earlier contributions of importance included the works of Torbern Bergman (1735–1784) in Sweden, who had described the apparatus and techniques for performing wet chemical analyses of minerals, including the alkali fusion method of bringing silicates into solution.

For his studies of meteoritics, Chladni himself gave full credit to Lichtenberg for providing him not only with information and ideas but with suggestions on how he could most profitably carry out an investigation of fireballs and fallen masses. Chladni clearly drew great inspiration from his conversations with Lichtenberg. Therefore, it comes as a surprise to us to learn that Lichtenberg himself left no record of his discussions with Chladni. In searching through his rather sketchy Staatskalender for 1789–1799, which consist mainly of names of persons he saw and letters he sent and received, we find that Lichtenberg listed seven meetings with

Chladni that took place between January 25 and February 8, 1793 (Promies 1971:770–771). On January 25 and 26, he noted visits by Chladni along with others; on January 28 he wrote that he spent an agreeable evening with him at The Three Princes; and on January 31 he heard Chladni play his instrument in public. A week later, on February 7, Lichtenberg remarked that Chladni brought him a copy of his essay, but he gave no indication of its topic. Finally, on February 8, Chladni called to bid him farewell and on that occasion, Lichtenberg gave him a letter of introduction to the astronomer Wilhelm Olbers in Bremen.

Chladni (1803:323) remarked that it was in February of 1793 that he conversed with Lichtenberg on fireballs and fallen masses. However, six years later, Chladni (1809:viii) recalled the date as being late in 1792. Thus, we may surmise that their discussion took place either on January 28, during their evening at The Three Princes, or on February 7 when Chladni handed Lichtenberg a manuscript on a subject he did not name. Possibly the manuscript was on a topic they discussed in January. Whenever it took place, their talk so excited Chladni that it set him onto a new career path. To Lichtenberg, however, the topic may have seemed too ordinary for him to mention it in his diary. Chladni (1819:6) wrote that after talking with Lichtenberg he spent three weeks at the library at Göttingen, so after bidding farewell to Lichtenberg on February 8, Chladni may have remained in Göttingen for three more weeks without calling upon him again while he diligently pursued his library research.

In any case, to borrow Hooykaas's phrase, meteoritics was in an embryonic state before Chladni published his book, and eight years later it was established as a new branch of scholarly inquiry. The recent 200th anniversary (in 1994) of the publication of Chladni's *Ironmasses* makes this an appropriate time to ask how much of the new science was founded upon his book? How did Chladni's contemporaries regard his ideas? Who else, or what other factors contributed to the origins of meteoritics? Would meteoritics have arisen when it did if Chladni had not written his book? How long did it take for meteoritics to gain recognition as an important branch of science? In seeking answers to these questions, this paper will review the beginnings of meteoritics over the turn of the nineteenth century and briefly trace ideas of meteorite origins up to the present time.

Meteoritics in the Late Eighteenth and Late Twentieth Centuries

One answer to the final question listed above is provided in the article on Chladni in the *Dictionary of Scientific Biography*, which aimed to summarize the lives and contributions of leading scientists around the world from the fifth century B.C. to 1990. The opening sentences on Chladni deliver a profound shock (Dostrovsky 1971, 3:258):

> Except for a few publications on meteorites, in which he proposed their extraterrestrial origin, Chladni devoted his research to the study of acoustics and vibration. His most important work was in providing demonstrations of the vibrations of surfaces, using the sand pattern technique which he devised.

So much for the "Founder of Meteoritics"! Indeed, so much for meteoritics! The science itself is given the back of the hand by this physicist, and, in effect, by the dictionary's editorial board headed by Professor Charles C. Gillispie, the distinguished scholar who introduced history of science as an academic discipline into the undergraduate curriculum at Princeton University in 1956, and into the graduate curriculum in 1960.

To a meteoriticist, Dostrovsky's statement reveals a breathtaking ignorance of Chladni's greatest accomplishments. But we scarcely could find a better illustration of how very inconsequential meteoritics appeared to some of our leading historians of science as recently as 1970. This tells us that nearly two centuries were to pass before the Space Age would establish meteoritics as more than a narrow specialty.

Today, meteoritics serves as a crucial link between astrophysics, planetary science, and earth science. Unfortunately, if meteoritics is gaining more notice from the broader scientific community and the public than it received in the biosketch of Chladni in the *Dictionary of Scientific Biography*, this may result not so much from discoveries of amino acids or extrasolar grains in meteorites as from the dramatic impact scenario for the extinction of the dinosaurs.

In Chladni's time, acoustics and meteoritics—the two new realms of inquiry to which he devoted his energies—were both very marginal to physics. Thus, although he was awarded a number of honors during his lifetime, Chladni never received a university appointment. To the day of his death at age 71, he earned his living by traveling over Europe with horse and carriage giving lectures and concerts. A letter dated June 22, 1824, from the physician-astronomer Heinrich Wilhelm Matthias Olbers (1758–1840) in Bremen to the brilliant mathematician Carl Friedrich Gauss (1777–1855) in Göttingen describes the situation (Schilling 1900, 2:321):

> Dr. Chladni is here again to give lectures on acoustics and meteorites . . . I have gladly given him his fee; only with the understanding that he will not require me to attend every one of his 12 or 14 lectures. It is truly sad that this, in many ways, deserving man has found no institution to award him a position with a salary, and at age 67 he must seek, in this way, to escape the miseries of poverty.

CHLADNI'S HYPOTHESES

Moving from Chladni's own fate to that of his ideas, let us examine his three hypotheses of 1794 that are accepted, wholly or in part, today. They are 1) masses of stone and iron do, in fact, fall from the sky; 2) they form fireballs as they

Ueber den

Ursprung

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und anderer ihr ähnlicher

Eisenmassen,

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Naturerscheinungen.

von

Ernst Florens Friedrich Chladni,

in Wittenberg, der Phil. und Rechte Doctor, der Berliner Gesellschaft Naturf. Freunde Mitgliede,
und der königl. Societät der Wissenschaften zu Göttingen Correspondenten.

Riga,

bey Johann Friedrich Hartknoch.

1794.

Fig. 2. The title page of Chladni's book, *Ironmasses*. . ., 1794. (From reprint edition, 1974, The University of Arizona Press.)

plunge through the atmosphere; 3) the bodies originate in cosmic space as either a) primordial masses that never aggregated into planets or b) fragments of planets disrupted by explosions from within or collisions from without.

Fireballs

Chladni devoted the first part of his book to a discussion of fireballs (Feuerkugeln) and meteors (Sternschnuppen-"shooting stars"), which he argued were similar phenomena except that the latter are small bodies that streak through the upper atmosphere and out again into space. Fireballs are spectacular phenomena that first appear as small points or streaks of light at very high altitudes and then expand in size as they plunge obliquely toward the Earth. Some were reported to surpass the diameter of the full Moon and the brilliance of the Sun. Typically, fireballs lost their luminosity several kilometers above the Earth and left behind long, smoky trails. Many fireballs were accompanied by thundering detonations and "horrid hissing sounds." Chladni listed the 20 best-described fireballs that were observed between 1676 and 1783, giving their estimated beginning and end points, apparent sizes, velocities, and the number and force of their explosions. Eighteen of the fireballs were observed in Europe and two in North America.

One particularly famous fireball discussed by Chladni (1794:13) streaked down the night sky at 10:30 P.M. on July 17, 1771. It first appeared over Sussex, England, passed over Paris, and ended with a huge explosion over Melun, France, 30 miles farther southwest. It caused such a sensation that the Académie Royale des Sciences commissioned Jean-Baptiste Le Roy (1720–1800) to conduct the first formal inquiry into the passage of a fireball. Observers told Le Roy that the fireball looked larger than the full Moon and changed its appearance before it exploded (Fig. 3). Some of them estimated that it traveled the entire 180 miles in four seconds. Faced with such an unimaginable velocity, Le Roy stretched the time to 10 seconds to yield the more credible velocity of 18 miles/second, which is equal to the orbital velocity of the Earth itself (Le Roy 1771:665). Some observers near Melun reported that a few glowing pieces seemed close to the ground after the fireball exploded, but Le Roy suggested that the explosion might have ignited some components of the lower atmosphere.

The apparent sizes of fireballs were as problematic as their velocities. Astronomers had determined the Moon's mean distance from the Earth as nearly 240,000 miles and its diameter at about 2,200 miles (Burke 1986:19). From this, they calculated that a fireball looking as large as the full Moon at an altitude of 55 miles must be half a mile in diameter. Le Roy estimated that the fireball of 1771 was 0.6 miles in diameter. Larger fireballs at lower altitudes were thought to be up to two miles in diameter. The obvious consequences if a fireball were to plunge into a city were not lost on anyone, but Le Roy assured his readers that no fireball could strike the Earth as a flaming mass because it would self-destruct on entering the dense lower atmosphere. Le Roy suggested that fireballs might be some kind of electrical phenomena, but he remarked, as scientists habitually do, that the subject needed more study.

Chladni systematically reviewed and rejected all the common explanations of fireballs—that they were related to the zodiacal light or the aurora, were clouds or streaks of inflammable gases in the upper atmosphere, or were manifestations of lightning or other electrical phenomena. He noted that several astronomers had surmised that fireballs were comet-like bodies orbiting the Sun. This idea granted a cosmic origin to fireballs but did not endow them with solid nuclei that could reach the ground.

Chladni declared that fireballs form when solid bodies traveling at cosmic velocities undergo frictional heating in the atmosphere. To account for their prodigious sizes, Chladni hypothesized (incorrectly) that, during flight, the solid masses heat to incandescence, melt completely, expand to enormous sizes, and explode from the build-up of gas pressures. As did all physicists of his time, Chladni thought in terms of ordinary combustion and assumed that the matter burning must be about the size of the fire.

Not until the mid-nineteenth century would scientists begin to understand that fireballs are incandescent auras of ionized atmosphere surrounding much smaller solid bodies, and that these bodies dwindle in size as thin layers of melt on their forward surfaces fly off in a trail of glassy droplets. Incandescence ceases when the bodies decelerate to the velocity of free fall. This commonly occurs at altitudes of 5–20 km above the Earth's surface—heights of the same order as those calculated for the end points of fireballs by Chladni and some of his contemporaries.

In our own time, scientists have learned that the detonations are sonic booms generated by shock waves set up by the body's supersonic flight in the atmosphere. Observers on the ground hear the terminal explosions first, sometimes followed by a great rumbling as a succession of shock waves arrives from higher and higher in the trajectory. The hissing and crackling sounds often reported by observers at close range during the passage of fireballs were either dismissed as imaginary or puzzled over from the early eighteenth until the late twentieth century when they first were ascribed to electrophonic effects by Colin Keay (1980).

Stones and Irons from the Sky

Fireballs are rare but they may be seen by thousands of witnesses. No one in Chladni's time disputed their existence. Falls of meteorites always are local events with few, if any, witnesses. They are easy to deny. In his book, Chladni recounted eyewitness reports of 18 falls of "meteorische Stein-und Eisenmasses" (the word "meteorite" was coined

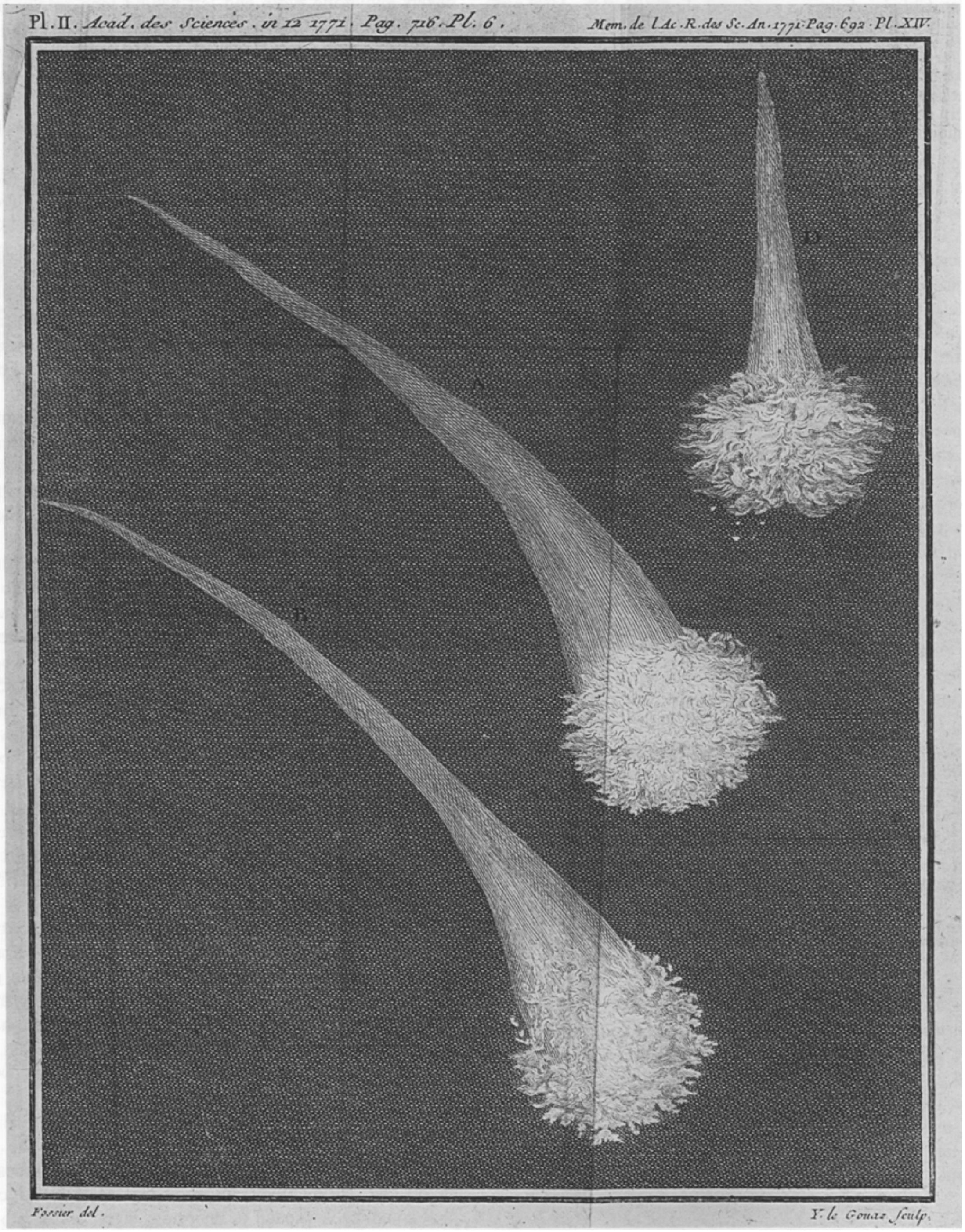


Fig. 3. Le Roy's illustration of the great fireball of July 17, 1771. His caption reads: "The different appearances in which it was seen. In the first, Figure A, it has assumed the shape of a drop before the explosion. In the second, B, it is pear-shaped just before the instant of explosion. The third, D, represents the meteor as it was seen by M. Landsman (Professor of Fortifications at the École Militaire), from Boulevard 9, sometime before the explosion." (There is no view C.) (From Le Roy 1771:716.)

later) beginning with the fall of an iron in Lucania about A.D. 56 and ending with the fall of a stone at Eichstädt, Bavaria, in 1785. He also discussed masses of so-called "native iron" that had been discovered far from any volcanic activity or sites of prehistoric smelting operations, and he argued that they, too, must have fallen from the sky. Several years later, Chladni (1797:29) wrote that when he finished his book he hesitated to publish it because of the hostile reactions to be expected. Why did he expect hostile reactions?

Toward the close of the eighteenth century, when Enlightenment ideas dominated thought throughout Europe, Chladni was reviving the ancient concept of things falling from the sky that had been dismissed a century earlier as a vulgar superstition. He also was gainsaying 2000 years of wisdom, inherited from Aristotle and confirmed by Isaac Newton, that no small bodies exist in space beyond the Moon. It is hard to imagine a more radical departure from a generally accepted body of knowledge than Chladni's.

Eighteenth-century physicists and astronomers were well aware that from time immemorial many peoples had believed in the fall of stones and fragments of iron from the sky—as well as in rains of blood, milk, wool, flesh, and gore—and that in both the old and the new worlds fallen irons had been venerated as signs from heaven and placed in shrines or burial mounds. In addition, certain rocky materials of odd shapes were believed to have fallen as "thunder-stones" or "lightning stones." Chief among these were objects we now recognize as belemnite fossils, globular concretions of pyrite or marcasite, fossil shark's teeth, and prehistoric hammers and axe heads. Depictions of such "falling stones" wreaking destruction on Earth are found in numerous old works (e.g., Fig. 4, upper), but close-up sketches of them (Fig. 4, middle and lower) were first published in 1565 by the Swiss natural historian, Conrad Gesner (1516–1565).

By the mid-eighteenth century, savants understood that minerals form within the Earth and fossils are petrified remains of living things. Contrary to expectations, observations in the Americas had shown that primitive men possessed both the skill and motivation to fashion stone implements without the aid of metal tools.[2] Consequently, they could not point to any objects in their natural history collections that necessarily had "fallen from the sky." Furthermore, most eighteenth-century scholars rejected an old belief that solid bodies can aggregate from dust within the atmosphere through the action of lightning or the combustion of flammable gases. That left no sources of supposedly fallen stones and irons except volcanoes and hurricanes. Ron Westrum (1978:467) pointed out that the naturalists of the time had shed the Renaissance fascination with ancient authors and popular lore, on which Chladni had relied almost exclusively, and had come to distrust any phenomenon that they could not subject to observation or experiment. They had no possible way of verifying eyewitness reports of falls, and so most savants of the Age of Enlightenment came to regard the very idea of objects from the sky as flouting both common sense and the laws of physics. An origin outside the atmosphere was not even to be considered.

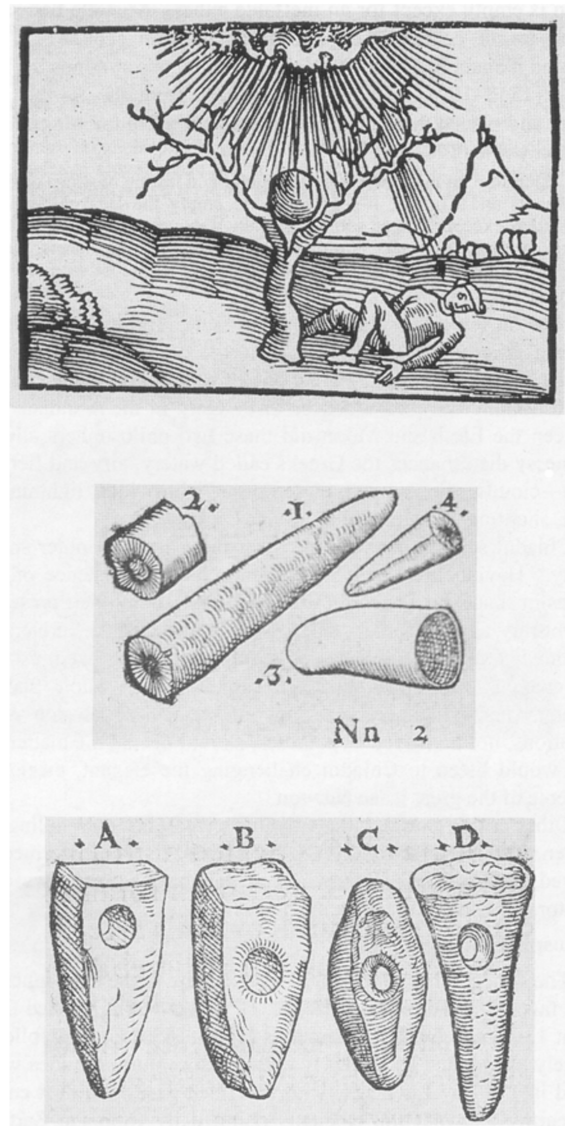


Fig. 4. Sixteenth-century sketches of fallen stones. Upper: An explosion in the sky expels a spherical ceraunia that splits open a tree while a small triangular glossoptera is about to dispatch a man already prone from the blast (Reich 1517; courtesy of Prof. Owen Gingerich, Harvard University). Middle: "Fallen belemnites" (Gesner 1565:91). Lower: One "Donneraxt" (Thunder axe) and three "Donnerkeil" (Thunder hammers). Stone "A" was said to have plunged through a windmill at Torgaw, Saxony, on May 17, 1561. Stone "D" split an oak tree with great force at Siptitz; the farmers dug it out and took it to the tax collector at Torgaw (Gesner 1565:64; courtesy of Smithsonian Institution Libraries). People marveled that these thunderstones looked so much like useful tools.

Cosmic Origin

When he spoke of cosmic space, Chladni's vision extended from the outer fringes of the Earth's atmosphere to the reaches of interstellar space. Noting that fireballs and shooting stars enter the atmosphere from every direction at velocities much higher than those attributable to the force of gravity, Chladni (1794:22) concluded that they are unrelated to the Earth or the Sun. He pictured them as small masses of primordial material that formed in deep space and never accumulated into planets, or as debris from the formation, destruction, and reaccumulation of planets, or of whole planetary systems.[3] Chladni (1794:85) postulated that the individual masses move through space in whatever direction they originally were propelled until they are captured by a large body.

With his hypothesis of cosmic origin, Chladni was challenging the almost universally accepted principle that aside from the great bodies—the fixed stars, comets, and planets—all space beyond the Moon is empty except for an ineffable aether. Aristotle had said so in the fourth century B.C., and Isaac Newton (1642–1727) had declared it again in 1704. By Newton's time, observations by Tycho Brahe (1546–1601) had removed comets from the Earth's atmosphere and placed them among the bodies beyond the Moon. Thus, Newton wrote (1704:367):

> Therefore, to make way for the regular and lasting Motions of the Planets and Comets, it's necessary to empty the Heavens of all Matter, except perhaps some very thin Vapours, Steams, or Effluvia arising from the Atmospheres of the Earth, Planets, and Comets, and from such an exceedingly rare aethereal medium as we describe above.

Newton felt that the aether was needed to transmit light and the force of gravity across the reaches of the cosmos. Like Aristotle, Newton viewed each of the great bodies as a self-contained entity to which nothing may be added and from which nothing may be lost. Only in the mundane realm between the Earth and Moon did these two philosophers allow all the messy disturbances the Greeks called watery, airy, and fiery meteors-clouds, rain, snow, hail, tempests, whirlwinds, lightning, aurorae, shooting stars, fireballs.

Chladni saw no physical basis for the claim that outer space is empty. Having presented his evidence for the existence of small bodies in space, he declared (1794:56) that to deny their presence is as arbitrary as to assert it; unless we assume that the universe has remained completely unchanged from the beginning, we must admit that changes have taken place in planets, or in whole planetary systems. The evidence, he said, favors the latter conclusion and observations, not unproved hypotheses, should decide the matter. But who would listen to Chladni challenging the elegant, mechanistic universe of the great Isaac Newton?

Other critics charged that Chladni's idea of bodies falling from heaven, and particularly his vision of planets being formed, destroyed, and formed again, violated the most sacred laws of the Creator. We shall hear from them below.

Atmospheric Origin

The concept that solid bodies may accrete in the atmosphere had been favored by Avicenna (980–1037), the Arabic scholar whose works reached Europe about 1300, and by the French philosopher and mathematician René Descartes (1596–1650) and his followers. Largely abandoned by the early eighteenth century, the idea was revived in 1789 by Lavoisier, who described in several passages how gases and dust containing earthy and metallic elements rise daily from the Earth and form inflammable strata above the ordinary air. Such strata, he said, could be ignited by electricity with consequent consolidation of metals and stony matter that produce fiery meteors (Lavoisier, Kerr translation, 1790:27–28, 58–59). Chladni totally rejected this mode of origin as being inadequate to create, instantaneously, solid stones and huge masses of iron.

CHLADNI'S COMPILATION OF WITNESSED FALLS

As noted above, Chladni (1794:37ff) listed 18 observed falls in all of history. He began his account with descriptions of two eighteenth century occurrences, one at Eichstädt, Bavaria, the other at Hraschina, Croatia, which he felt presented the most persuasive evidence favoring his hypothesis that stones and irons actually do fall from the sky. For his information on these falls, Chladni quoted extensively from a paper *On Some Stones Allegedly Fallen from Heaven* published in 1790 by the Abbe Andreas Xavier Stütz (1747–1806), then serving as Assistant Director of the Imperial Natural History Cabinet at Vienna.

Eichstädt, Bavaria, 1785

Stütz wrote that in 1785 he received a small piece of stone from his friend the Baron Homspech, Canon of Eichstädt and Bruchsal in Bavaria. Stütz described the sample as ash-gray sandstone with tiny grains of malleable iron and iron ochre scattered through it. He said it had a thin, sulfurous crust of malleable native iron, resembling a blackish glaze streaked with traces of fiery melt. A notarized document he received with the stone stated that at 12:00 P.M. on February 19, 1785, a day when the countryside was covered with a foot of snow, a worker at a brick kiln saw it fall from the clouds after a violent thunderclap. The man rushed to the spot but found the black stone too hot to pick up until it cooled in the snow. The document stated that the country rock of that area consisted chiefly of fossiliferous marble that was entirely different from the stone.

Tabor, Bohemia, 1753

Stütz remarked, in passing, that the Baron Ignaz von Born (1742–1791), a previous director of the Imperial Cabinet, had described a specimen in his private collection consisting of refractory iron ore mixed with greenish stone and covered with a slaggy crust that had been found near Tabor in Bohemia. Chladni (1794:31) quoted von Born's notation in his catalog: "some credulous people claimed that the stone had fallen from heaven in a thunderstorm on July 3, 1753." Chladni accepted the claims of the credulous people that a stone fell—but not from a thunderstorm.

Hraschina (Agram), Croatia, 1751

The reports from Eichstädt and Tabor reminded Stütz of a 71-pound mass of iron in the Imperial Cabinet that likewise was said to have fallen from heaven many years earlier near Hraschina, in the Bishopric of Agram, Croatia. With respect to that mode of origin, wrote Stütz (1790:399): "many a mouth already has been distorted with derisive smiles." He added that if fairly distinct effects of fire were visible on the Eichstädt specimen, they were unmistakable on this one, much as they are on the mass of iron found in Siberia by the celebrated Pallas, except that here the impressions are larger and shallower. Stütz observed that the Agram iron lacks the yellow glass of the Siberian mass and the stone of the one from Eichstädt. (Clearly, no sharp distinctions were drawn at that early date between masses of metallic iron, stony irons, and stones with iron grains).

With his interest aroused, Stütz retrieved from the archives a Latin document that had been sent to the Imperial Cabinet in 1751 along with the large iron. It quoted the sworn testimony of seven witnesses, from widely separated localities, of a spectacular event that occurred about 6:00 P.M. on May 26, 1751. Indeed, immense detonations had caused such alarm over so wide an area that the imperial couple, Emperor Franz I and Empress Maria Theresa, had ordered the investigation. Stütz translated the document into German and published it along with the description of the Eichstädt stone. He would leave it to his readers, he remarked, to draw their own conclusions as to the facts presented.

In the testimonials, collected for the Bishop of Agram, the witnesses were unanimous in saying they had heard an enormous explosion and seen a brilliant ball of fire burst into two balls linked by fiery chains (Fig. 5). A great rumbling followed as of many carriages rolling along. Some of the witnesses saw a large mass of iron fall into a newly plowed field where it split a large cleft in the ground, scorched the soil, and made the ground shake like an earthquake. Others saw a smaller mass fall into a meadow. Stütz (1790:407) wrote:

> The artless manner in which the whole thing is described, the agreement of the witnesses who had absolutely no reason to agree on a falsehood, and the similarity of the story with that of Eichstädt makes it seem at least probable that something real lay behind the accounts.

By "something real," Stütz was not referring to falls, however. He continued:

> Of course, in both cases it was said that the iron fell from heaven. It may have been possible for even the most enlightened minds in Germany to have believed such things in 1751 due to the terrible ignorance then prevailing of natural history and practical physics; but in our time it would be unpardonable to regard such fairy tales as likely. However, it is a large step from disbelief of tales to the discovery of the true cause of a phenomenon that seems to us miraculous. And probably I should have committed the error, into which we so naturally fall concerning things we cannot explain, of denying the whole history rather than being prepared to believe anything so incredible, if various new writings on electricity and thunder had not, fortunately, come into my hands at that time. Particularly the remarkable experiment of Komus that reduced iron oxide to metal . . . Lightning is an electrical stroke on a large scale: if the reduction of iron oxide can be obtained by the discharge of an electrical machine, why should not this be accomplished with much greater effect by the very powerful discharge of lightning from the clouds?

Stütz preserved the large specimen of the Hraschina iron (Fig. 6) (a class IID medium octahedrite), and the Eichstädt stone (an H5 chondrite), both of which may be seen today in the Natural History Museum at Vienna. In response, Chladni wrote (1794:33):

> I am not astonished at the aversion this competent doctor (Stütz) shows to relating these phenomena to circumstances that seem contrary to accepted ideas, and by his effort to explain them by the ordinary principles of physics. I do not wish to reveal a lack of the knowledge prevailing in this century when I defend the exactitude of the circumstances reported and argue that these masses are truly fallen from the atmosphere, or might be part of a bolide, and by no means are the product of lightning.

Pre-Eighteenth-Century Falls

Chladni found records of ten falls reported in the first through the seventeenth centuries. Most of them were cursorily described and remained unsubstantiated, but he said they merited citation because their accounts shared one or more similarities with those of the Agram and Eichstädt falls: a violent thunderclap in a serene sky, a sky with one small cloud, a great fire in the sky, hard or metallic stones with black crusts, sulfurous smells, and stones too hot to touch.

Ensisheim, Alsace, 1492

The 280-pound stone that fell at Ensisheim on November 7, 1492, is the only one in Chladni's pre-eighteenth-century list of which specimens are preserved today. This stone quickly became famous because it caught the attention of a king—Maximilian (1459–1519), the "Roman King," who was heir apparent to the Holy Roman Emperor, Friedrich III. Maximilian was leading his army toward Ensisheim, a Free Imperial City of the Hapsburgs, on his way to battle the French. On his arrival, he sent for the stone and asked his advisors what it meant. After solemn reflections, they told him, as clever advisors have done throughout history, that the stone was a pledge of God's favor to him. Greatly pleased, Maximilian returned the stone to the citizens of Ensisheim with orders to preserve it in their church as a memorial of this great, miraculous event.

Presently, Sebastian Brant (1457–1521) at Basel, the leading poet of the time, rushed into print two broadsheets describing the fall in Latin and German verses and prophesying victory for the king (Brant 1492). In an early exercise in publicity and propaganda, pirated broadsheets, bearing Brant's name, and similar verses, soon appeared in two other cities, Reutlingen and Strassburg. Maximilian won his impending battle (chiefly because his troops possessed a large cannon they aimed toward a narrow defile), and soon afterward, Brant issued another broadsheet celebrating his victory and declaring that the stone promised good luck to Maximilian throughout his life. Subsequently, the fall of the stone would appear in paintings and engravings as well as in the chronicles of numerous central European cities (Marvin 1992; 2006:16–24).

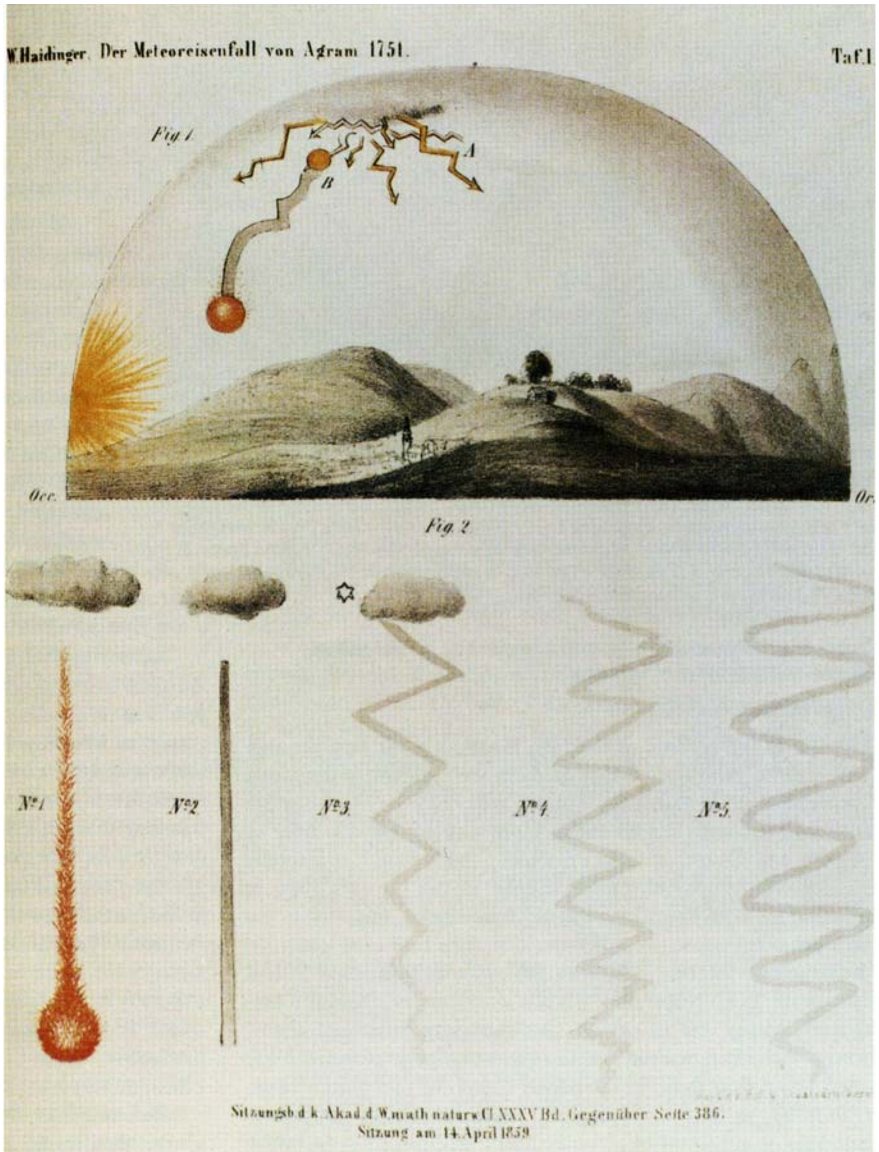


Fig. 5. "Two painted plates depicting the phenomena of Agram (1751)," a handwritten notation by Paul Maria von Partsch, Director of the Imperial Natural History Cabinet in Vienna, on a folder in the archives containing these two pictures. They show the fireballs and smoke trail as seen from near Szigetvár, 15 miles southeast of Hraschina, about 6:00 P.M. on May 26, 1751. Upper: A high cloud expells flashes like lightning (A), and a fireball (B) bursts into two balls linked by intertwined fiery chains. Lower: As seen from Szigetvár, the fireball appeared to fall straight down from the cloud (1). The straight, smoky trail shortly after the fireball burned out (2). As the evening star appeared beside the cloud, the trail grew fainter and assumed a zig-zag shape (3). As night came on, the cloud disappeared and the trail grew dimmer, longer, and its angles more rounded (3 and 4). These depictions were duly attested to by five witnesses. (Chromolithograph from Haidinger 1859:389).

In retrospect, we may appreciate the fact that the stone survived at all. A young boy was the sole witness of the plunge of the huge black stone into a field, making the ground shake. He aroused the citizens who dragged it out of its shallow hole and then fell upon it, hacking off pieces to carry away as magic, or medicine, or keepsakes. Fortunately, it was a large stone and the Landvogt soon arrived on the scene and forbade further destruction. He ordered the stone to be moved into the city and placed at the door of the church.

Three hundred years later, Chladni (1794:35) remarked that the great triangular stone still was attached by an iron chain in the parish church of that place. However, in 1793, while he was writing his book, French revolutionaries liberated the stone from clerical authority and placed it on public display in nearby Colmar. There, pieces were taken off as gifts for important visitors, including Chladni himself, who obtained a fragment weighing 450 grams. Chladni did not mention the enormous explosion, heard over much of the upper Rhineland, or the fireball that heralded the Ensisheim fall. However, he took pains to correct his source materials, one of which dated the fall in 1493, another in 1630. Chladni (1794:35) said we could deduce the actual date of fall from

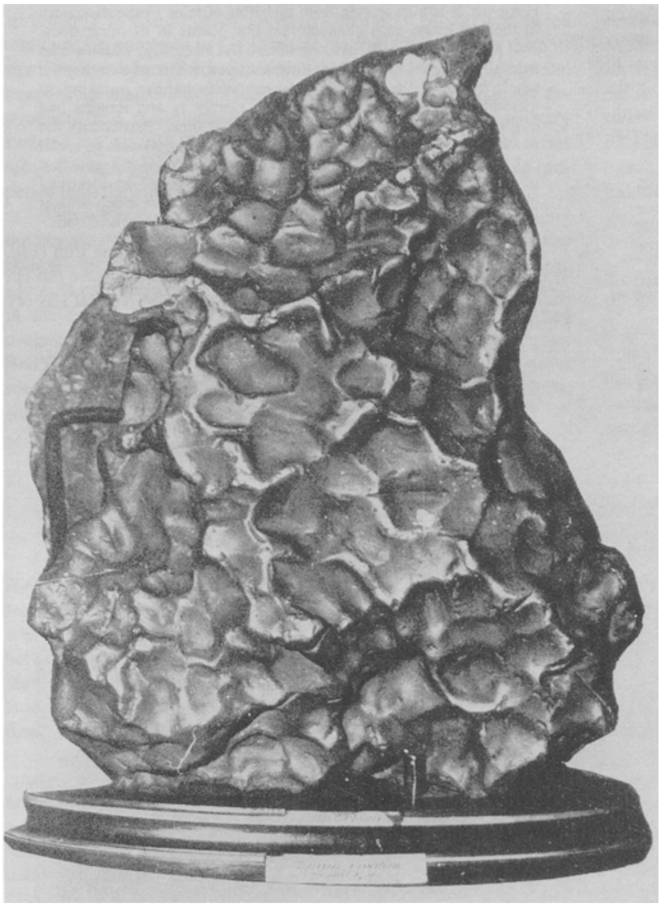


Fig. 6. The larger of the two Hraschina irons listed by von Schreibers as weighing 71 Vienna commercial pounds; cataloged today (Graham *et al*. 1985:170) as weighing 40 kg (88 English pounds). Note Widmanstätten figures in the small, etched space at top where a small piece was sliced off. The iron is on display in the Natural History Museum in Vienna. (Plate 1 from the supplement to Chladni's book of 1819 by von Schreibers 1820).

the following chronogram, mounted near the stone, which declares that a stone weighing twice one-hundred pounds fell from the sky at Ensisheim. Excluding the E in Ensisheim, the capitalized letters—taken individually with no pairing and no subtractions—sum to 1492:

Centenas bIs habens rVpes en saXea Libras
EnsheMII eX CoeLI VertICe Lapsa rVIt

Today, the remaining 123-pound main mass of the stone of Ensisheim (an LL6 chondrite) is on display in the historic Palais de Régence in Ensisheim where the museum was refurbished in time for the celebration of the 500th anniversary of its fall (Marvin 1992). As noted above, the stone of Ensisheim was the first witnessed fall in the West from which pieces are preserved. Indeed, it was believed to be the first in the world until scientists learned in 1979 of a stone preserved in a Shinto Shrine at Nogata-shi, Japan, for which credible dating methods confirmed an oral tradition that it had been seen to fall on May 19, A.D. 861. The stone was analyzed for its chemical and isotopic composition, classified as ordinary L6 chondrite, and returned to the shrine (Shima *et al*. 1983; Marvin 2006:16–22).

Additional Eighteenth-Century Falls

By the eighteenth century, records were much improved of the events Chladni took to have been falls. In addition to those reported by Stütz at Agram, Tabor, and Eichstädt, Chladni listed the following five, all of which now are cataloged as genuine meteorites.

Pleskowitz, Bohemia, 1723

On June 22, 1723, at about 2 o'clock on an afternoon of serene weather, with only one small cloud in the sky, a loud peal of thunder heralded the fall of stones at Pleskowitz in Bohemia. No flash of light was reported. Twenty-five stones of different sizes were collected at one site and seven or eight at another. All of them were black on the outside, metallic on the inside, and exhaled a strong odor of sulfur. Today, some 35 g of Pleskowitz (or Ploschkovitz), an L5 chondrite, are catalogued in various museums.

Albareto, Italy, 1766

In July 1766, a 12 kg stone fell at Albareto in the Duchy of Modena. Chladni (1794:37) listed it but provided no details of the event. He had not yet seen the 120-page book issued in 1766 by the Abbé Domenico Troili (1722–1792), who investigated the circumstances of the fall. Terrified witnesses told Troili they heard a tremendous explosion followed by whistling sounds, like those of a cannon ball coursing through the air. Next, they saw a body falling out of the sky—some said it was fiery, others that it was dark and emitting smoke. (Both could have been right: it depends on where the witness is situated with respect to the falling body.) A single stone plunged a meter deep into the soil, making the ground shake. Bystanders retrieved the stone and said it was warm to the touch and smelled of sulfur and bitumen. Then they hacked it to pieces and carried the fragments all over the town.

Fortunately, Troili obtained a sample and examined it under his microscope. He described it as looking like a buffy sandstone with scattered grains of a brassy mineral he called "marchesita," an old name for pyrite. In an effort to explain the fall of the stone as due to natural, rather than supernatural, causes, Troili designed his book as a philosophical treatise in which each proposed mode of origin was refuted until the only one left was volcanism. He concluded that the stone had explosively risen into the sky from a vent in the Earth.

For this idea, Troili was severely criticized by Bishop Giuseppi Fogliani of Modena, who claimed to have a much better explanation: the bishop argued that a bolt of lightning had struck through the stone, which was metallic, as it lay on the sodden ground that typified the Albareto region. The water scattered and the stone rose into the air while covered by its own flash so it could not be seen until it fell back again.

In response, Troili (1767) prepared a 71-page *Lettera Apologetica*, proffering all due respect to the bishop but stoutly defending his own hypothesis of a volcanic origin. Before he sent *Lettera* to the bishop, Troili, who was librarian to the Duke of Modena, discovered in the archives a copy of a recent letter, dated 1767, by Giovanni Battista Beccaria (1716–1781), professor of physics at the University of Turin, to Benjamin Franklin (1706–1790). In it, Beccaria favored Franklin's ideas on the nature of electricity over those of his rivals. More specifically, he supported the bishop's idea that the stone of Albareto had been hurled aloft by lightning. On reading that, Troili sat down and added an 8-page P.S. to his *Lettera Apologetica*. In it, he pointed out to the bishop that a single flash of lightning would not suffice; as far away as Modena, the duke's gardener said he had been terrified that a cannonball from the nearby fortress of Mirandola, might land in his garden. In the spirit of the Enlightenment, both Troili and the bishop (who did not publish his argument) sought for natural causes of the fall, so neither of them could have envisioned an origin in the skies.

Nearly 30 years later, Chladni, who was unaware of Troili's book, read a reference to Beccaria's lightning bolt explanation of the fall at Albareto. Never doubting that the stone was a meteorite, Chladni (1794:37) asked if Beccaria supposed that huge masses such as the fifteen-ton iron in South America had been borne aloft by lightning and dropped from the sky. About 15 years after that, Chladni read Troili's book and devoted nearly a full page to it in his book, *Über Feuer-Meteore und die mil denselben herabgefallenen Massen*, published in 1819.

In 1863, the brassy mineral Troili called marchesita was identified as stochiometric FeS, for which Wilhelm Karl Haidinger (1795–1871), the curator of the Imperial Mineral Collection in Vienna, proposed the name "Troilite." Haidinger wished to honor Troili as the first person to describe that mineral, and also as the first to record the actuality of meteorite falls a generation before Chladni did. Haidinger was well aware that Troili himself did not think of the stone as a meteorite. In fact, he quoted Troili's own argument for a volcanic origin, but he reasoned that inasmuch as we know the Albareto stone was a meteorite, and we know it came from space, we should give priority to Troili for his early description of a meteorite from space.

Haidinger did a disservice to meteorite studies with his application of hindsight, which historians call "presentism." Presentism is anathema to modern historians who go to great efforts to place each person's ideas and accomplishment in the context of his or her own time. Unfortunately, Haidinger's approach has been pursued by others in recent years. In 1952, the American meteorite collector and researcher, Harvey H. Nininger (1887–1986), wrote that although we generally credit Chladni as the first person to properly evaluate the arrival of meteorites from space, Troili had written a perfectly valid account of a fall thirty years earlier and furnished a mineralogical description of the material from that fall. Chladni, he said, had relied mainly on the large list of records made by other men. Twenty years later, Nininger (1972:7) wrote that Troili correctly deduced that the Albareto meteorite came from space. More recently, Peter H. Schultz (1998:107), of Brown University, supported Nininger as rightfully crediting Troili instead of Chladni with the pioneering breakthrough of describing a fall and proposing a cosmic origin! Schultz compiled a table titled: "Turning points (conceptual breakthroughs and discoveries; independent of consensus views)" with Troili at the top of the list for his linking, in 1766, of meteorites to cosmic debris! Neither Nininger nor Schultz could have written what they did if they had read Troili's book or Chladni's. Both would have understood that Troili argued repeatedly for a volcanic origin of the Albareto stone, and that, far from simply compiling lists of old falls, Chladni was first to apply the principles of physics by which he linked meteorites with fireballs, and deduced their origins in space from their high velocities and their flight paths which enter the atmosphere from every direction. Chladni, alone, deserves full honors as the first person to investigate meteorites and to propose their origin in space. Today, the largest remaining specimen of Albareto (an L5 chondrite) is a 600-gram piece in the University Museum at Modena (Marvin and Cosmo 2002).

Lucé 1768, Nicorps 1750, Aire-sur-la-Lys 1769, France

Chladni ended his list with three falls named for the provinces of France where they fell: Maine, Cotentin, and Artois. In the autumn of 1768, the Royal Academy of Sciences received a fragment of a stone from a corresponding member, the Abbé Charles Bachelay, who stated that it fell from the sky at Lucé in Maine about 4:30 P.M. on September 13. He reported that several harvesters, startled by sudden thunderclaps and a loud hissing noise, looked up and saw the stone plunge into a field where they found it half-buried and too hot to pick up. The sky was clear. No high cloud, fireball, or lightning flash were reported. The academy requested an examination of the Lucé stone by a committee of three members: the chemists August-Denis Fougeroux de Bonderoy (1732–1789), Louis-Claude Cadet de Gassicourt (1731–1799), and Antoine-Laurent de Lavoisier (1743–1794). Incidentally, two years later, the academy would commission Le Roy's investigation of the great fireball of 1771 (see Fig. 3), but Westrum (1978:464) observed that the academy saw no connection between a "fallen stone" and a fireball—at the time they had no basis for making one.

The First Chemical Analysis of a "Fallen Stone," 1769

The analysts did not think of it as such, but Lucé was the first "fallen stone" to be analyzed by essentially modern chemical methods. The chemists described the stone as partially covered with a thin black crust over an interior of gray cindery material scattered with an infinite number of shiny metallic points of a pale yellowish color. They performed bulk analyses first by wet and then by dry techniques that yielded three constituents: vitrifiable earth 55.5 wt%, iron 36%, and sulfur 8.5%.

Although Lavoisier was a newcomer to the Academy and the junior member of the committee, he read the report to the academy on April 15, 1769. The full report, dated July 1772 and authored by Fourgeroux, Cadet, and Lavoisier was not published until 1777 in volume 2 of the *Journal de Physique, de Chemie, et d'Histoire Naturelle*, which was founded that year. In it, the authors concluded that the stone from Lucé was not a thunder stone and had not fallen from the sky; it was a fragment of pyrite-rich sandstone that had been struck by a bolt of lightning. They suggested that the bolt had blown away a thin covering of soil and melted the surface of the stone, but the heat was too transitory to penetrate the interior. Today, this can be read as the first statement that interiors of stony meteorites are not melted.

While they worked, the chemists received a second stone from M. Morand-le-fils, who said it had fallen near Coutances in the Cotentin Peninsula of lower Normandy. They observed that the black-encrusted stone from the Cotentin emitted a less sulphurous odor but was similar in other respects to that from Lucé. This coincidence led Fourgeroux *et al*. (1777:255) to declare: "We do not believe that one can conclude anything else from this resemblance except that the thunder struck preferentially on pyritiferous rocks."

The Royal Academy received a third stone that fell at Aire-sur-la-Lys in Artois too late for it to be included in the paper. However, Fourgeroux and Cadet analyzed it and reported that the stone from Artois was essentially identical to those from Lucé and Cotentin. They remarked that perhaps one day studies of such stones will throw new light on the nature of electricity, lightning, and thunder itself.[4] Fourgeroux and Cadet presented their results to the Academy on August 2, 1769 (Smeaton 1957:228). The report remains unpublished, but a copy obtained from the archives of the academy was made available for this study by D. W. G. Sears in 1996 (personal communication).

Although the academy did not issue a memoir on this subject, a brief note titled *Three Curious Events of the Same Kind*, presumably written by the secretary of the academy, G. de Fouchy, appeared in the history of the academy for 1769 (published in 1772). After summarizing the observations and chemical results, the note stated that the academy was far from concluding that the three stones were produced by thunder. But the similarity of events in widely separated places, and the perfect resemblance between the stones and their differences from other stones appeared to be sufficient grounds for publishing this note and inviting physicists to submit anything new on this subject; perhaps they could shed new light on the electric fluid and its action on thunderstones (Burke 1986:34).

Incidentally, the stone they received from Morand-le-fils was listed as "Coutances" or "Cotentin" until 1802, when Joseph-Jêrome de Lalande (1732–1807), wrote that this probably was the stone that fell with a loud explosion near Nicorps, in the Cotentin, on 1750 October 11 (Lalande 1802: 452). Although this event had taken place 52 years earlier, his suggestion was generally accepted, and the stone has since been called "Nicorps." Today, samples of the Lucé stone, an L6 chondrite, are found in several museums. Those from Nicorps and Aire-sur-la-Lys are long lost but are believed to have been genuine meteorites.

Barbotan (Agen), France, 1790

Chladni did not include this fall in his list, presumably because the news did not reach him in time. It is important to our history, however, because of the widespread publicity it received and the diverse responses to it.

At about 9:30 P.M. on July 24, 1790, a brilliant fireball with a long, luminous trail was seen for nearly 50 seconds over a large area of southern France. An enormous explosion heralded the fall of stones over several villages in the vicinity of Barbotan and Agen. Excited stories circulated widely, and Pierre Berthelon (1741–1799), editor of the *Journal des Sciences Utiles* in Montpellier, published reports of the event. Word of his accounts reached his friend, Jean F. B. Saint-Amans (1748–1831), who said later that he sought to match this absurdity with an authentic act by demanding an official testimonial to the event. Much to his surprise, Saint-Amans received a notarized deposition in short order, signed by a mayor and his deputy, stating that at least 300 citizens had witnessed the fall. Seeing the deposition as nothing but new proof of the credulity of country people, Saint-Amans induced Berthelon (1791:228) to write:

> How sad, is it not, to see a whole municipality attempt to certify the truth of folk tales . . . the philosophical reader will draw his own conclusions regarding this document, which attests to an apparently false fact, a physically impossible phenomenon.

Five years later, certain editors still felt the same way. In 1796, Nicolas Baudin, professor of physics at Pau, published a detailed description in *La Décade* of the fall at Barbotan, which he had observed while strolling with a friend in the grounds of the Chateau de Mormes. Baudin (1796:388) wrote that just after the great fireball exploded, sending echoes rumbling along the Pyrenees, a quantity of stones had fallen near Juliac and Barbotan. To this statement, the editors appended a footnote:

> The author of the memoir appears persuaded that, in effect, a fall of stones occurred immediately following the explosion of the meteor, and he goes to great pains to explain their formation; he would have been more philosophical to doubt the fact in the first place. As for us, in spite of so many well-affirmed certificates; in spite of so many pretended examples of showers of stones, we do not place any faith in them. The noise that these meteors make in bursting, the dazzling light that they spread, the surprising shock they cause stuns the majority of those that see them: they do not doubt that the burst had fallen all around them; they run, they look, and if they find by chance some stone that is a little bit black, they say that

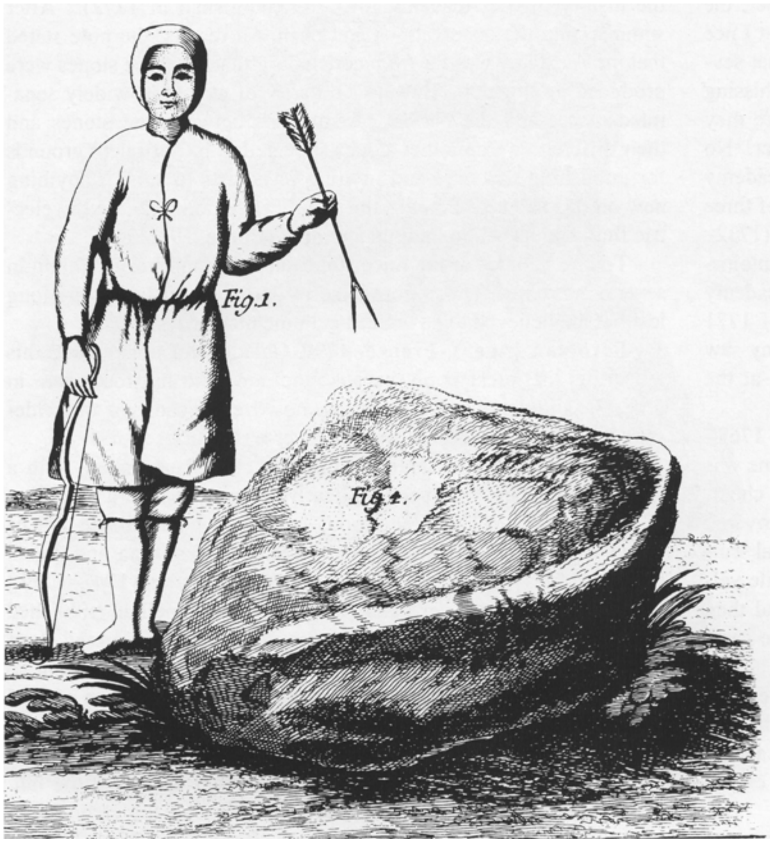


Fig. 7. Sketch by Pallas of the mass of iron as he saw it in Krasnojarsk, Siberia. No hint is visible of the striking porosity of the mass. The figure has no relationship with the meteorite: it is one of several depicting local costumes. (From Pallas 1776, vol. 3, plate 3, p. 68; courtesy of the Houghton Library, Harvard University.)

> surely this stone just fell. If the fable spreads, all the country will look for such stones, and will find thousands. . . . A meteor quite like that which makes the object of this memoir appeared about 24 years ago above Paris . . . and many very reliable persons in Paris certified that the flaming material had been thrown out by the explosion almost into their bedrooms. (Note des Auteurs de *La Décade*.)

It was into this intellectual climate that Chladni introduced his book.

NATIVE IRONS

The Pallas Iron, Siberia, 1772

As noted above, Chladni's book title referred to a 1600-pound mass of iron described in the book of travels through Siberia by Peter Simon Pallas (1741–1811), a German professor of natural history at St. Petersburg. In 1749, the heavy mass had been found lying on a high ridge of Mt. Bolshoi Emir by Yakov Medvedev, a local blacksmith, who was showing the iron-rich bedrock to Johan Mettich, a government mining engineer. Intrigued by its metallic content, Medvedev returned the next winter and expended enormous energy, most likely with the aid of a horse, transporting the mass down the slopes and across more than 30 kilometers of frozen ground to his home in the village of Ubeisk (Krinov 1960:10). Medvedev failed to forge the metal because it was too malleable before heating and too brittle afterward, so he placed it outside his house. The local people revered it as a sacred gift from heaven.

In 1772, Pallas arrived at Krasnojarsk, the administrative center of the region, and sent an aide southward to explore the area. At Ubeisk the mass caught the attention of the aide, who immediately recognized it as material worthy of study and carried, or sent, a sample to Pallas. Pallas customarily kept detailed records of his itineraries, but he wrote nothing about making a trip to Ubeisk or to the find-site on Mt. Bolshoi Emir. Nevertheless, he described these localities in such detail that some Russian scientists believe he must have gone there (Gallant 2002:121). Pallas described the bedrock of Mt. Emir as gray schist banded with blue-black magnetic ore assaying 70% of iron. He reported signs of forest fires near the find site but no evidence of volcanic activity or of primitive smelting operations. He sampled and sketched the mass (Fig. 7) and described it as rough as a sponge, riddled with cavities, many of which were filled with amber-yellow glassy-looking material (Fig. 8). He regarded the mass as a remarkable instance of the work of nature—most likely formed in a

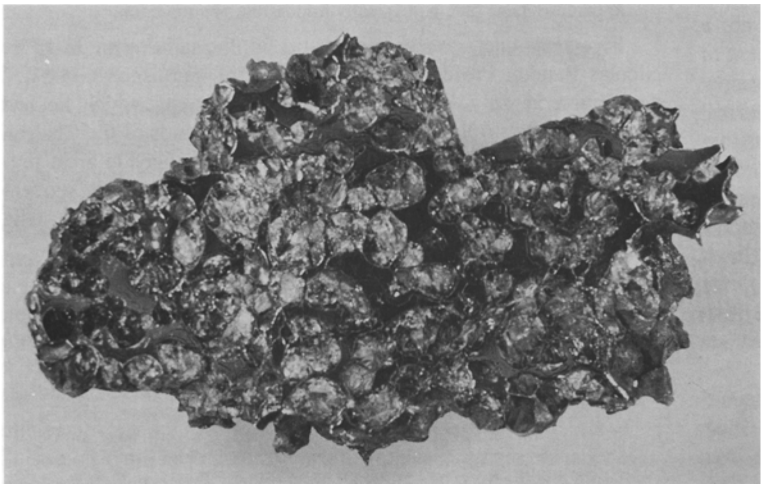


Fig. 8. A fragment of the Pallas iron (Krasnojarsk), about 8 cm across, showing the rough, cellular nickel-iron metal enclosing crystals of olivine. (Courtesy of the Department of Mineral Sciences, Smithsonian Institution.)

pocket of a vein long since eroded away. In 1773, Pallas arranged for the mass to be transported from Ubeisk 230 kilometers northward to Krasnojarsk. From there, it was shipped to the Imperial Academy at St. Petersburg where it arrived in 1776 and was displayed in the Kunst Kammerer, a hall of curiosities begun by Peter the Great (Krinov 1960:11).

Between 1773 and 1787, Pallas distributed samples of the mass to scientific societies and to leading scientists throughout Europe, including one to Chladni before he wrote his book (Czegka 2001:A46). In 1825, Gustav Rose (1798–1873), director of the Mineralogical Museum of the University of Berlin, classified all stony-iron meteorites of this type as pallasites.

The Pallas iron was a striking example of those enigmatic bodies called "native irons," which had long puzzled natural philosophers. Were they the work of nature or of artifice? Consisting largely or wholly of malleable metal, these unrusted masses always occurred as exotics—entirely unlike the country rocks of the region where they lay. Clearly, they once had been molten, but similar metal masses were not found at the vents of active volcanoes. Their huge sizes and frequently remote locations made production by ancient smelting operations appear extremely unlikely, and, in any case, metallic iron produced artificially was "known" to be not malleable but brittle. Nevertheless, in seeking explanations for native irons, savants of the late eighteenth century often spoke of extraordinarily powerful ancient volcanoes, vanished artisans with advanced technologies, or bolts of lightning on iron ore or pyrite.

From Pallas's description of the mass, Chladni argued that the local people were correct: the iron mass must have fallen from the sky. He pointed out that it showed evidence of fusion, so it could not have been deposited from an aqueous solution. It lay among schistose mountains and was too distant from volcanoes or inflammable coal seams to have been created by natural modes of combustion. Forest fires or bolts of lightning would be entirely inadequate to melt and reduce bedrock to metallic iron under any circumstances. And the Pallas iron was by far too heavy and in too remote a location to have been created by ancient smelting operations, which, in any case, should have separated out the yellow mineral and robbed the metal of its malleability. Chladni (1794:40) called the yellow component "olivine" before he ever saw a sample of the Pallas iron. The fusion of the metal, Chladni said, must have taken place in a fire more intense than any known on Earth—a fire that, somehow, left it malleable. Chladni concluded that this "native iron" was cosmic matter that had heated to incandescence and melted while plunging through the atmosphere in a fireball.

Did Chladni See the Pallas Iron?

Chladni visited St. Petersburg in 1794 May, the month after the publication of *Ironmasses*. The purpose of his trip was to demonstrate his keyboard instrument, the euphonium, which he played to enthusiastic listeners including the empress Catherine the Great. Did Chladni, who was a corresponding member of the Russian Academy, examine the Pallas iron during his visit? Of course he did, we respond; indeed, we envision him rushing to see the mass as soon as he arrived. However in 1958, Friedrich Adolf Paneth (1887–1958) raised this question, in all seriousness (see Dingle *et al*. 1964:207). Paneth noted that Chladni, who faithfully reported his trips to examine meteorites and described his own sample of the Pallas iron, never wrote that he had seen the main mass. Instead, Chladni relied on Pallas's descriptions, using some of his words and phrases, not only in his *Ironmasses* of 1794, before he went to St. Petersburg, but also in his *Feuer-Meteore* of 1819. In response, Hoppe (1979:95) argued that in 1815 May, Chladni described a sample of the Pallas iron in the Berlin Museum as a very rare piece taken from the outer surface of the mass where it was more scoriaceous. Hoppe thought that Chladni could not have known about its surface characteristics unless he had seen the main mass. The question remains open.

Today, the largest remaining portion of the meteorite, weighing about 1,135 pounds, is at the Academy of Sciences in Moscow. Smaller pieces are in museums and other collections around the world. In 1980, Russian scientists undertook the immense effort of commemorating the discovery of the Pallas iron by mounting a cast-iron disk, two meters across and stamped with a design showing a fireball and a fallen iron, on a cement base at the find-site on the high ridge of Mt. Bolshoi Emir (Gallant 2002:139).

The Mesón de Fierro, Campo del Cielo, Argentina

Chladni reasoned that the huge mass of iron that lay in the flat, powdery soils of the northern Argentine Chaco also must have fallen from the sky. Well known to the nomadic peoples of the region, the mass was first seen by Europeans in 1576 when Capitán Hernán Mexía de Miraval led a small contingent of Spanish soldiers out of the fortified settlement of Santiago del Estero on a long, dangerous march to the site where their guides said they obtained the metal in their weapons. He reported finding a large mass of iron rising out of the ground like a great monument, with smaller pieces lying around it. The Indians said the iron had fallen from the sky amid raging fires, but de Miraval assumed he had found the surface exposure of an iron mine. He carried samples back to Santiago where a blacksmith found it to be iron of exceptionally high purity.

Despite the fact that he had found native metal instead of iron ore, the Spanish authorities had no interest in developing an iron mine at that time and place. So de Miraval's official records of his discovery were deposited in the Archivo General de lndias in Seville, where they would lie unread until the early 1920s (Alvarez 1926). Today, they rank as the earliest documentation of the finding and sampling of a meteorite by Europeans in the Americas.

Two-hundred years passed before don Bartolomé Francisco de Maguna, entered the Chaco in 1774 and came upon what he described as a large, nearly smooth bar or plate of metal, sloping upward out of the ground. This one soon became known as "el Mesón de Fierro" (the table of iron). Great excitement ensued when news came from Madrid that the metal assayed 80% iron and 20% silver! It seemed that the Argentine Chacos might be richer than the Andes of Peru! However, analyses made in Buenos Aires and at the historic mining locality of Uspallata in the Andes, yielded no silver at all. One more expedition led by don Francisco de Ibarra in 1779 returned with samples lacking silver. Nevertheless, in 1783 the Viceroy at Buenos Aires sent Lieutenant don Miguel Rubín de Celis, of the Royal Spanish Navy, to measure the extent of the ore body and, if it proved promising, to found a colony at the site. De Celis led 200 men from Santiago del Estero into the Chaco where he dug up the mass and exploded gunpowder in the hole. When he failed to find any extension at depth or to either side, he estimated its weight at 15 metric tons, made sketches of it (Fig. 9), and abandoned it as worthless. Despite occasional rumors to the contrary, no one ever has seen el Mesón de Fierro again. Perhaps de Celis tilted the mass back into its deepened hole where it gradually was covered by mud from seasonal flooding and overgrown with the thorny bushes of the Chaco. But neither mud nor bushes should conceal a huge mass of iron from airborne magnetometers which have been used extensively during the past few decades. Fortunately, de Celis had taken samples, reportedly wearing out 70 chisels to obtain 12 kilograms of the metal. In 1788, de Celis sent reports of his expedition, in Spanish and English, to the Royal Society, which published them in *Philosophical Transactions* (de Celis 1788:183–189). He also sent specimens that were displayed at a meeting of the society and later presented to the British Museum.

From the first, the indigenous peoples had said that the iron had fallen from the sky. The Spanish rejected that idea out of hand, but they did call the area Campo del Cielo (Field of the Sky), which is a translation of the Indian name for it. De Celis scouted the unpromising region for a volcano. Presently, two leagues to the east, he found a brackish spring at a gentle rise of about five feet above the plain. This, he concluded, must be the worn down remnant of the ancient volcano that erupted the gigantic mass of native iron (de Celis 1788:371). (He relied upon an 18th century belief that mountains are destroyed from within by volcanic fires originating in burning coal seams, e.g., Taylor 1979).

Chladni (1794:40) would not hear of such an idea. He wrote (1794:40) that the iron mass fell from the sky in a fireball. Today, Chladni's opinion has been fully vindicated. More than 60 metric tons of fragments of a coarse octahedrite (class IAB) and 20 shallow meteorite craters have been found at Campo del Cielo in a strewn field 75 km long (Cassidy *et al*. 1965). In recent years, meteorite collectors scavenging the strewn field have recovered hundreds of mostly small irons (e.g., Notkin 2006), but they have failed to find el Mesón de Fierro. Perhaps we may wonder if there ever was a single large iron seen by several explorers. Perhaps de Miraval, de Maguna, de Ibarra, and de Celis happened upon different large specimens; certainly their descriptions of them differ considerably.

The largest Campo del Cielo iron known today was never seen in Colonial times. It was discovered in 1966 when a metal detector received a strong signal from an iron buried beneath the floor of Crater No. 10 in the midst of the strewn field. In 1969 the Argentine army excavated the huge iron from a depth of five meters. Named El Chaco, it weighs 33 tons and ranks as one of the largest meteorites in the world — second only to the 60-ton Hoba iron in Namibia. Carbon-14 measurements on three fragments of charred wood from within a rim and beneath a crater floor indicate that the fall

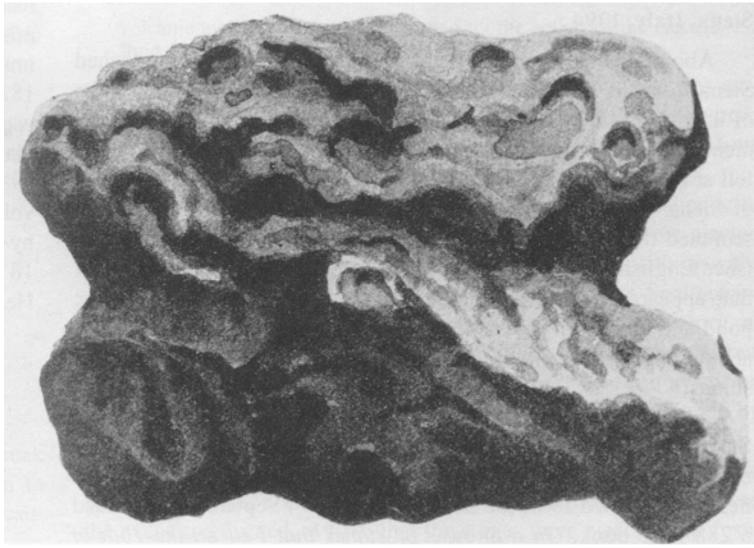


Fig. 9. A sketch by don Rubín de Celis of el Mesón de Fierro. He reported its maximum width as 3.54 meters and estimated its weight as about 15,000 kg. This specimen seems too lumpy to be described as a "Table of Iron," but de Celis assumed it must be the same one given that name by don Francisco de Maguna in 1774. (From Alvarez 1926.)

occurred about 4000 years ago (Cassidy 1993, personal communication). Thus, it is possible that ancestors of the indigenous people actually witnessed the spectacular fall at Campo del Cielo (Marvin 1994).

The Aken (Aachen) Mass

Chladni discussed a third large mass of iron, weighing 15,000 to 17,000 pounds, that reportedly was dug up in 1762 from under the pavement at the city of Aken in the Duchy of Magdeburg. He examined a small sample of this metal in a mineral collection at the University of Wittenberg. Subsequently, Chladni (1819:346) wrote that the identity of the sample was mistaken, the weight of the mass was much smaller than reported, and the actual site of its discovery was in Aachen (Aix-la-Chapelle). Ultimately, this iron mass was dismissed as an artifact.

Chladni spoke of other "native irons," mostly with attached scoria, that were not meteorites. Toward the end of his book, Chladni (1794:59) observed that fallen bodies are principally composed of iron, an element that is abundant in the Earth's crustal rocks, a key component in all living things, and one that we must suppose makes up a considerable portion of the Earth's interior, as indicated by the presence of the magnetic field. He then suggested that elements such as sulfur, silica, and magnesia may not be limited to our Earth but very likely also occur in the materials that make up the celestial bodies. His insights mark a preliminary approach to planetary science.

GERMAN RESPONSES TO CHLADNI, 1794

As noted above, Chladni remarked in 1797 that after writing his book he hesitated to publish it because of the hostile reactions to be expected. However, on careful consideration, he concluded that the phenomena he described could not properly be explained in any other manner without either contradicting observations already made or well-known laws of nature. He retracted nothing. However, without having personally observed a meteorite fall, or even examined a meteorite, he had only hearsay evidence with which to document his case at a time when his learned contemporaries had long since dismissed all reports of fallen stones, ancient and modern, as figments of superstitious imaginations.

In Germany, the first review of Chladni's book appeared in the August 11, 1794, issue of the *Göttingen Notices on Learned Subjects*. After a brief summary of Chladni's main arguments linking fireballs with fallen bodies of cosmic origin, it concluded in a derisive tone (p. 1286):

> One must admit that his hypothesis and his application of it are sharp-witted. To assume materials whose existence is by no means proved but are essential to the hypothesis, and to add forces and motions according to the needs of the hypothesis, leads easily into the pitfall of the Cartesian philosophy that is out of style. However, its use has become so common to explain chemical, electrical, magnetic etc., phenomena, that one cannot deny these liberties with physics to Mr. Chladni's hypothesis.

Two months later, on October 10, Alexander von Humboldt (1769–1859) wrote to his friend Carl Freiesleben in Freiberg (Hoppe 1979:26): "By all means, read Chladni's infamous book on iron masses." Within the next decade, however, Humboldt would come to accept meteorites. In 1799, he began five years of travels in the Americas, which would bring about profound changes in his ideas. He switched from being a devoted Neptunist to a Vulcanist when he was confronted with the immensity of active and extinct volcanism in the Cordilleras of South and Central America. During his travels, he read the European literature on meteorite falls and finds, and their chemical analyses. In 1804, he sent for a sample of a huge iron, El Morito, which had been known in Mexico since 1600. He carried home several kilograms that he gave to the chemist Martin Heinrich Klaproth (1743–1817) in Berlin. Years later, in the first volume of *Kosmos*, his five-volume survey of the Earth in the universe, Humboldt (1845) praised Chladni for his “remarkable acuteness” in linking fireballs with stones which have been known to fall through the air.

Throughout 1794, Chladni’s book received negative reviews in Germany. German scientists felt that Chladni’s use of historic eyewitness reports, which they equated with folk tales, and his flouting of the rules of the Aristotelian-Newtonian view of the cosmos made his new theory totally unacceptable (Hoppe 1979:27). From the first moment, however, at least one of Chladni’s colleagues, Johann F. Blumenbach (1752–1840), a physicist and natural historian at Göttingen, welcomed the book for its new hypothesis on the origin of meteorites. In an unpublished letter, dated 24 September 1794, that was recently discovered by Wolfgang Czegka, of Potsdam, in the archives of the Royal Society, Blumenbach wrote to Sir Joseph Banks that he had been most pleased, during his recent trip to London, to receive from Banks a specimen of the famous mass of iron from a desert in South America, and also one of the mass found by Pallas in Siberia. “You know,” wrote Blumenbach, “how enigmatical these phenomena have been for the mineralogist, but now I think myself very happy to send you the key to this riddle” (Czegka 1999:A29):

> one of our natural philosophers, Dr. Chladni, who demonstrated with an immeasing [amazing?] apparatus of learning & sophistry that these Iron-masses belong by no means to mineralogy, but to meteorology & astronomy . . . they were not formed in the earth, nor in the atmosphere of our planet, but in the remote cosmical regions . . . these little lumps were hardly any thing else, but metallized shooting stars.

With this letter, Blumenbach enclosed a copy of Chladni’s book. Across the bottom of the letter, Banks wrote: “Thanks for books,” but no letter of thanks from Banks to Blumenbach has been found in the archives.

This episode tells us that the earliest copy of Chladni’s book to reach England lay unpublicized and possibly unread for more than two years. Indeed, before any responses to Chladni’s book appeared in print, a spectacular shower of stones occurred at Siena in Tuscany.

TWO WITNESSED FALLS, 1794–1795

Siena, Italy, 1794

About 7:00 P.M. on June 16, 1794, a high cloud approached Siena from the north, emitting smoke, sparks like rockets, and bolts of unusually slow-moving red lightning. Suddenly, a series of tremendous explosions rent the air, the cloud flamed red, and hundreds of small stones fell at the feet of men, women, and children at Cosona, about 14 km southeast of Siena. One stone reportedly pierced a boy’s hat and scorched the felt while others singed leaves on trees. Two astonished English ladies saw stones fall into a pond that appeared to boil. Subsequently, the government drained the pond and recovered the stones, which were selling to English tourists at such high prices that a lively trade sprung up in simulated fallen stones (Chladni 1797:18).

A Dissertation by Ambrogio Soldani, September, 1794

In Siena, the Abbé Ambrogio Soldani (1736–1808), professor of mathematics at the university, compiled reports from numerous witnesses, examined 19 of the stones, and in September 1794, he issued a 288-page book, *On a Shower of Stones that Fell on the 16th of June at Siena*. In it, he detailed the circumstances of the fall and the sizes, shapes, and distribution of the stones, which ranged from a few ounces to seven pounds. Soldani included one large foldout plate (Fig. 10) with engravings of the high cloud and five fallen stones. To him, their forms suggested triangular pyramids and parallelpipeds indicative of a strong impetus toward crystallization. Soldani concluded that the stones had aggregated from metallic and earthy dust within the fiery cloud.

Soldani sent a stone to a mineralogist, Guglielmo Thomson, in Naples who studied it in detail and described it in seven letters that Soldani included in his text. He said the stone had a black crust and gritty, “quartzose” interior scattered with pyrites. He crushed a sample, drew a magnet through the powder, and made the first recorded mineralogical separation of grains of a fallen stone. He identified the magnetic components as iron in a state of perfect malleability. With this observation Thomson proved conclusively that the stone differed from all known rocks. Thomson signed his letters to Soldani as Guglielmo (the Italian equivalent of William), or simply as G. Thompson. (In most of his later letters and his publications he dropped the “p” in favor of his authentic surname, Thomson.)

In a postscript to his letter of August 26th, Thompson (1794a) wrote (in Soldani 1794:264) that a friend, who did not wish to be named, had suggested that the Sienese stones had been projected beyond the lunar sphere of attraction by the process described by the celebrated Herschel; furthermore, at the time of the eruption, the Moon must have been at its zenith directly over Italy so that the stones were attracted to that spot on our globe. The celebrated Herschel to whom Thompson referred was the German-born astronomer-musician, William Herschel (1738–1822), residing in England, who had discovered the planet Uranus in 1781. Herschel (1787:230) reported observing four volcanic eruptions on the Moon between 1783 and 1787. Although Thompson presented it as

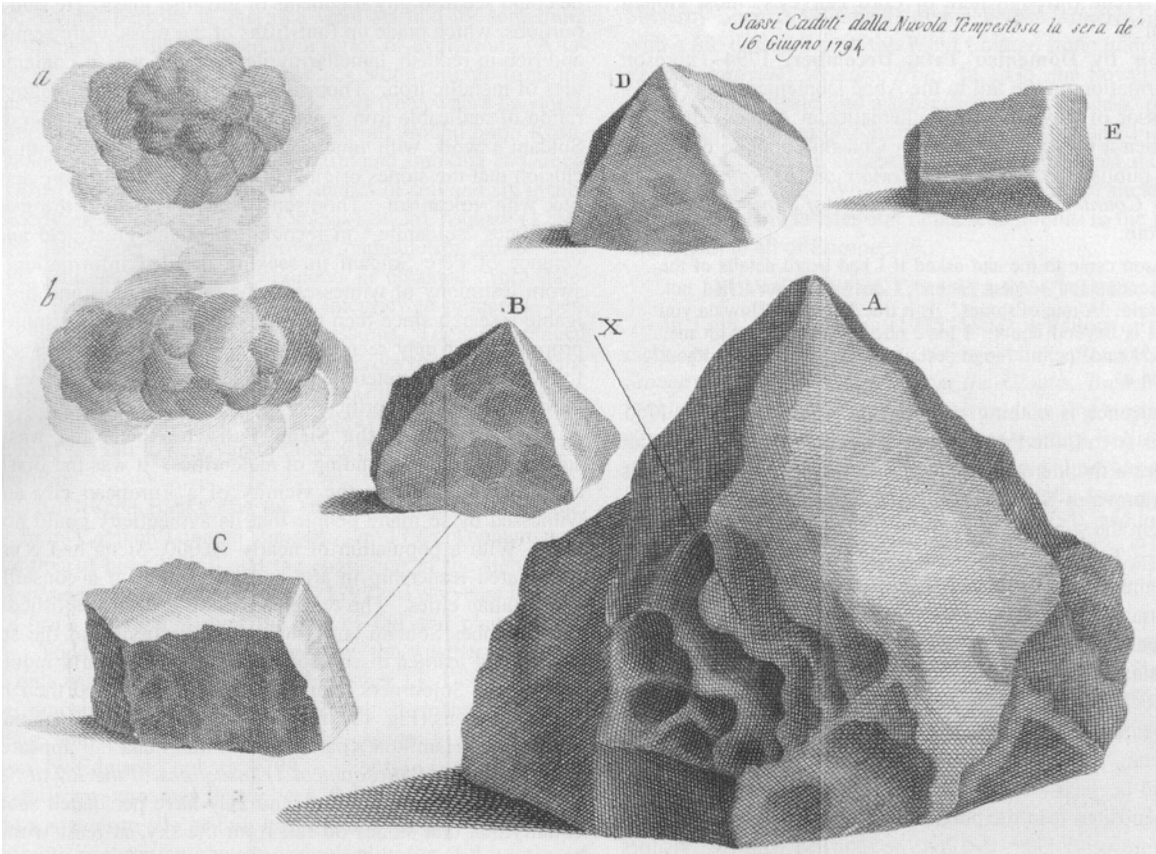


Fig. 10. "Stones fallen from the stormy cloud on the 16th of June, 1794": Soldani's title to the plate in his book. The individual engravings are: (a) Sketch of the high dark cloud as it first appeared approaching Siena from the north, (b) The cloud a little later, after it had spread horizontally. Of the stones in the Siena shower, A, weighing five pounds, was the largest one seen by Soldani. He described it as tending toward a pyramid with a flat, quadrangular base. Stone B was much smaller, tending toward a triangular pyramid with a base Soldani called a quasi-hexagon approaching a parallelpiped. Stone C was a broken fragment with a quadrilateral shape that was something like the base of B. Stones D and E are stones that, in Soldani's view, approach a pyramid and parallelpiped. (Endplate from Soldani [1794] courtesy of the Smithsonian Institution Libraries.)

a suggestion by an anonymous friend, his letter contained the earliest published speculation in modern times that fallen stones might have come from a lunar volcano.

A Memoir by Domenico Tata, December 1794

In December 1794, one more book on the Siena fall was published in Italy by the Abbé Domenico Tata (1723–1800), professor of physics and mathematics at Naples. It was his 74-page *Memoir on the Rain of Stones Fallen in the Countryside of Siena, the 16th of June, 1794*. In it, Tata (1794:14) wrote:

> Mr. Thomson came to me at my house and asked if I had heard details of the curious phenomenon seen at Siena. I answered that I had not. Thomson said: 'A rain of stones,' 'Is it true?' I asked, 'How do you know?' 'It is beyond doubt. I have one of the stones with me.' 'Well then,' I said, 'permit me to describe that stone to you without having seen it.'

This occurrence is nothing new, declared Tata. Back in December 1755, his friend, the Prince of Tarsia, had told him of the fall of a stone after a thunderous detonation on the previous July at his estate at Terranova di Sibari in Calabria. Five shepherds saw the fall and brought the stone to him. On hearing the tale from the naive young cavalier, Tata said he scarcely could contain his laughter; he only asked if the prince would send him the stone and an eyewitness report. One month later he had the stone in his hand, along with a notarized document supplied by the highly respected agent of the house of Tarsia. The stone was nearly spherical and covered with a dark crust except where a piece had broken off when it struck the ground. It weighed about seven and one-half pounds. After examining it in detail, Tata placed the stone in an elegant glass case in which it could be seen on all sides without being touched. Subsequently, he deposited it in the public library where it would be well cared for. Nine years later, in 1764, he returned with two visitors and found the stone partly covered with a white efflorescence and beginning to crumble. (The efflorescence, consisting of magnesium carbonates and sulfates, occurs on a small percentage of stony meteorites and ultimately destroys them.) On a later visit, Tata found the stone had disappeared; probably, he said, because one of the custodians found the disintegrating stone to be useless and wanted to use the case for something better. Tata (1794:23) was convinced of the authenticity of this fall and he said he had intended to publish a full description of it but was dissuaded by friends who warned him that he would be ridiculed by "Savants" and, worse yet, by "Half-Savants" who are the more to be feared.

Tata (1794:28) also mentioned the report by Abbé Andreas Stütz in 1790 of the alleged falls at Hraschina in 1751 and Eichstädt in 1785. He said he had learned of these events from a letter written to Thomson by Captain François Tihausky, the director of His Majesty's Cannon Foundaries in Naples. Stütz himself had denied that these events were actual falls from the sky, but four years later the situation looked different to the scholars in Italy; they took the reports from eastern Europe as confirmation of falls as valid natural phenomena.

Tata's treatise included a more complete mineralogical description by Thomson than the earlier ones he had sent to Soldani. Thomson (1794b) (in Tata 1794:51–70) said the stones had dark, slaggy surfaces and granulated interiors with light and dark portions separated along curving surfaces, typical of semi-liquid or pasty material. The light portions, the color of ashes, resembled quartose sand cemented with clay and scattered with grains of iron, pyrite with a dark-purplish luster, and red-ochre spots, probably of decomposed pyrite. Using a loupe he also could see tiny fragments of greenish glass. He said the dark portions, which made up 4/5ths of the mass, were semi-vitrified and rich in reddish, lamellar pyrite, some of which contained globules of metallic iron. Thomson again described his magnetic separation of malleable iron grains. Both Tata and Thomson discussed Soldani's work with much admiration and agreed with his conclusion that the stones originated within the atmosphere and had no link with volcanism. They proposed to name the material of the stones "soldanite," in recognition of the great zeal and perseverance of Pére Soldani in seeking detailed information through sworn testimony of witnesses to the rain of stones and his indefatigable research since then to clarify all aspects of the subject. Thomson first published the name, "soldanite," in the *Giornale Letterario di Napoli* (1796, v. 61:17–21). He published it again for a wider readership in *Bibliothèque Britannique* (1804, v. 27:144–145). Appropriate as it may seem to name this rock for the first scholar to fully document a meteorite fall, "soldanite" did not survive for long in the annals of meteoritics.

A Report on the Siena Fall by Sir William Hamilton, 1795

Soldani dedicated his book to a distinguished resident in Siena, Frederick Augustus Hervey (1730–1803), the 4th Earl of Bristol and Bishop of Derry, to whom he had sent a detailed account and a stone. On July 12, Hervey sent the stone and a description of the fall (which he said took place amidst a most violent thunder storm) to Sir William Hamilton (1730–1803), the English Ambassador to the Court of Naples, who is remembered chiefly today as the husband of the renowned beauty, Emma Hamilton, who later became mistress to Lord Horatio Nelson. Hamilton did not receive the letter immediately because Hervey sent it via Sir Joseph Banks (1743–1820), the president of the Royal Society in London. Banks forwarded the letter and stone to Hamilton with remarks to the effect that the old bishop must be telling tall tales (Pillinger and Pillinger 1996). Meanwhile, Hamilton, who was instrumental in turning volcanology into a modern science, was diligently observing the day-by-day activity of Mt. Vesuvius which had sprung into full eruption on June 15, 18 hours before the fall of stones at Siena. This circumstance, wrote Hervey (in Hamilton 1795:103),

> . . . leaves a choice of difficulties in the solution of this extraordinary phenomenon . . . either these stones have been generated in this igneous mass of clouds . . . or, which is equally incredible, they were thrown from Vesuvius at a distance of at least 250 miles; judge then of its parabola[5] . . . My first objection was to the fact itself, but of this there are so many eye-witnesses, it seems impossible to withstand their evidence, and now I am reduced to a perfect scepticism.

Introducing the subject as "a very extraordinary circumstance indeed . . . although it might have no relation to the eruption," Hamilton inserted a single paragraph concerning the fall at Siena into his 43-page report on the eruption of Mount Vesuvius that appeared in the *Philosophical Transactions of the Royal Society* of February 1795. After quoting from Hervey's letter, Hamilton (1795: 104) gave his own impressions of the stones:

> The outside of every stone . . . ascertained to have fallen from the cloud near Siena, is evidently freshly vitrified and black, having every sign of having passed through an extreme heat; when broken, the inside is of a light-gray color mixed with black spots and some shining particles, which the learned here have decided to be pyrites, and therefore it cannot be a lava, or they would have decomposed . . . stones of the same nature, at least as far as the eye can judge of them, are frequently found on Mount Vesuvius; however, when I was lately on the mountain, I searched for such stones near the new mouths but found none because of thick beds of new ash . . . if similar stones with vitrified coats were to be found on Vesuvius, the matter of origin would be decided in favor of Vesuvius-unless it could be shown that another vent had opened closer to Siena, such as that of Mount Radicofani (a long-dormant volcano) which lay within 50 miles of that city.

As he wrote these observations, Hamilton (1795:105) was struck with another idea: inasmuch as quantities of ash were known to have been carried to greater distances than that between Mt. Vesuvius and Siena,

> . . . might not the same ashes have been carried over the Sanese (*sic*) territory, and mixing with a stormy cloud, have been collected together just as hailstones are sometimes . . . and might not the exterior vitrification of those lumps of accumulated and hardened volcanic matter have been occasioned by the action of the electric fluid on them?

Hamilton remarked that Father Ambrogio Soldani, who was currently printing his dissertation on this event, believed that the stones were generated, independently of volcanic assistance, in the igneous mass of clouds from which the stones fell.

After the fall at Siena, no one in Italy disputed the authenticity of fallen stones. Arguments focused on whether they were ejected by volcanoes or had coagulated within the atmosphere, with or without the presence of volcanic ash. One scholar, Lazarro Spallanzani (1729–1799), the distinguished professor of natural history at Pavia, rejected both volcanoes and dusty clouds as meteorite sources. He declared that the stones that fell over Siena had been swept up from the ground by a local hurricane and singed on the outside by atmospheric electricity.

A scientist who positively favored a volcanic origin was Georgio Santi (1746–1822), professor of botany at Pisa, who had witnessed the event and argued, at first, that the stones were ejecta from Vesuvius; later he postulated that they came from a submarine eruption near Siena. Santi compiled reports from Siena, Florence, Pisa, and other localities, and sent information and more samples of stone to William Thomson. It all began, wrote Santi (Tata 1794:11) with the appearance of a little cloud, dark and menacing, while the rest of the sky was serene. He made no mention of Lord Hervey's "most violent thunder-storm," which no one else spoke of either, most likely because it was a figment of Hervey's imagination.

Significance of the Siena Fall

The Siena fall was of key significance in the founding of meteoritics (Marvin 1998). It was the first in modern times to occur in the vicinity of a European city and to be witnessed by so many people that its authenticity could not be denied. With a population of nearly 30,000, Siena had a university and shared leadership in arts and sciences with a constellation of other Italian cities. The two treatises on the fall published in 1794 by the Abbés Soldani and Tata raised discussion of the subject to the level of learned discourse and prompted scholarly inquiry internationally. Sojourners returning from Siena carried their tales and their specimens (Fig. 11), real and bogus, home with them. When Sir William Hamilton's paragraph on the Siena fall appeared in the February 1795 *Philosophical Transactions of the Royal Society*, it persuaded some of his countrymen that stones do fall from the sky—at least within a few hundred kilometers of active volcanoes—and it also carried the news to Germany, where it caught the attention of Wilhelm Olbers in Bremen.

The Siena fall inspired two youthful English naturalists to take an interest in meteorites: William Thomson (1760–1806) and James L. Macie (about 1765–1829). Thomson was a mineralogist and a physician who studied medicine at Edinburgh and Oxford, and played a strong role in natural history societies. Through these activities he met Macie. They became friends and continued to exchange specimens as long as Thomson lived. Thomson earned his Doctor of Medicine degree from Oxford in 1786 and was elected as physician to the Radcliffe Infirmary at Oxford, and as a Fellow of the Royal Society that same year. Thomson then embarked on a promising career of practicing medicine, teaching anatomy and surgery, and presenting what appears to have been the earliest lecture course on mineralogy at Oxford. Then, in September 1790, Thomson abruptly resigned his positions at Oxford and his fellowship in the Royal Society, and left England for the continent.

Fig. 11. A stone from the historic fall at Siena, 1794. (Courtesy of Robert Hutchison, British Museum of Natural History, London.)

In April 1792, after more than a year spent visiting savants in Paris, Siena, Florence, and Rome, Thomson took up residence in Naples, where he was welcomed by the flourishing community of nearly 60 English residents. In addition to writing the earliest mineralogical descriptions of the stones that fell in Siena, he took a strong interest in the eruptions of Mt. Vesuvius and accumulated a famed collection of lavas and ash, and of natural and artificial materials that had reacted to hot lavas and gaseous emanations. Leading geologists from Europe and America came to Naples to see his collections and learn about his classification system. Meanwhile, Thomson practiced medicine with such skill that he gained the confidence of the pope, who named him Physician-in-Ordinary.

However, with French forces occupying Turin and Rome, Naples was under constant threat of invasion, so in 1798 Thomson fled to Sicily, along with the king and queen of Naples and all their court on a boat commanded by Lord Horatio Nelson. Thomson returned to Naples in 1801, bringing new types fossils to describe. Under repeated threats, he left for Sicily again in 1803 and did not return. Thomson died in Palermo in January of 1806 at the early age of 46. We shall encounter him again when we discuss the metallurgy of the Pallas iron.

In 1801, James L. Macie assumed the surname Smithson after the deaths of both of his parents. In 1765, he had been born out of wedlock to Hugh Smithson, the first Duke of Northumberland, and Lady Elizabeth of the illustrious Macie family. Macie was a dedicated naturalist and collector of minerals and fossils. When the stones fell in Siena, Macie was in nearby Florence, from which he rushed to the scene. The Siena stones whetted his interest in meteorites, which he continued to collect throughout his lifetime. Smithson, who died in 1829 with no direct heirs, had the unique vision to bequeath his entire property to a nephew with the stipulation that, if the nephew were to predecease him without progeny (which he did), his estate would go to the United States of America to found in Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men.

After some years in Chancery Court in England, and prolonged debates in Congress, the Smithsonian Institution was founded in 1846. Smithson's property, consisting of more than $500,000 in gold, 10,000 mineral specimens including meteorites, and Smithson's books, letters, and manuscripts, was shipped to Washington. Though many of the tangibles, including its meteorite specimens, were lost in a fire in 1864, the Smithsonian Institution grew into a complex of museums and research stations dedicated to science, history, and the arts (Ewing 2007). A history of its extensive meteorite collection, which currently receives an annual influx of fragments from the USA-led expeditions to Antarctica, is described by Clarke, Plotkin, and McCoy (2006).

Wold Cottage, England, December 1795

As though to quell any remaining doubts about falls of stones from the sky, nature intervened again—this time in Great Britain, herself.

At 3:30 on Sunday afternoon December 13, 1795, a 56-pound stone fell at Wold Cottage in Yorkshire. The sky was overcast. Suddenly, several persons in the area were startled by something whizzing through the air followed by a series of explosions. A laborer looked up just in time to see a black stone emerge from the clouds and plunge into the soil about 30 feet from where he stood. The ground shook, and mud and sod flew up all around him. Rushing to the spot, he found a large stone that he said was warm and smoking and smelling of sulfur. It had penetrated twelve inches of soil and six inches of the underlying limestone. Soon after the fall, the landowner Captain Edward Topham (1751–1820), a flamboyant pamphleteer, editor, and playwright, moved from London to his estate at Wold Cottage. He had seen notices in the London papers of the dramatic event on his property in Yorkshire, and he applied his talents toward generating further publicity. Topham obtained sworn statements from the three eyewitnesses and interviewed numerous persons who had heard sounds or felt concussions. Six months later, he arranged to exhibit the stone in Piccadilly, London, across the street from the much-frequented Gloucester Coffee House (Pillinger and Pillinger 1996). He prepared a handbill with an engraving of the stone and a description of the fall to be given to those who paid the entrance fee of one shilling.

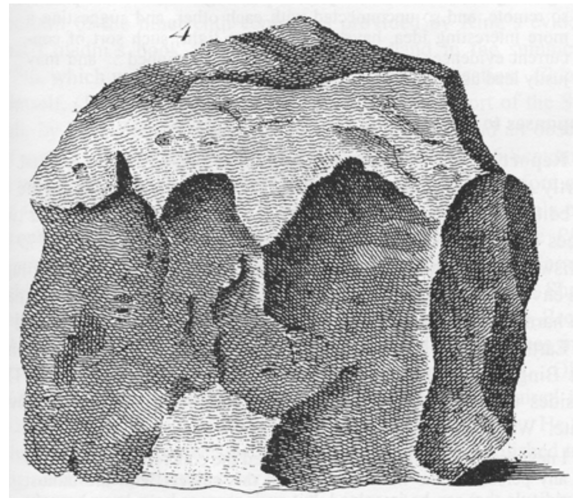


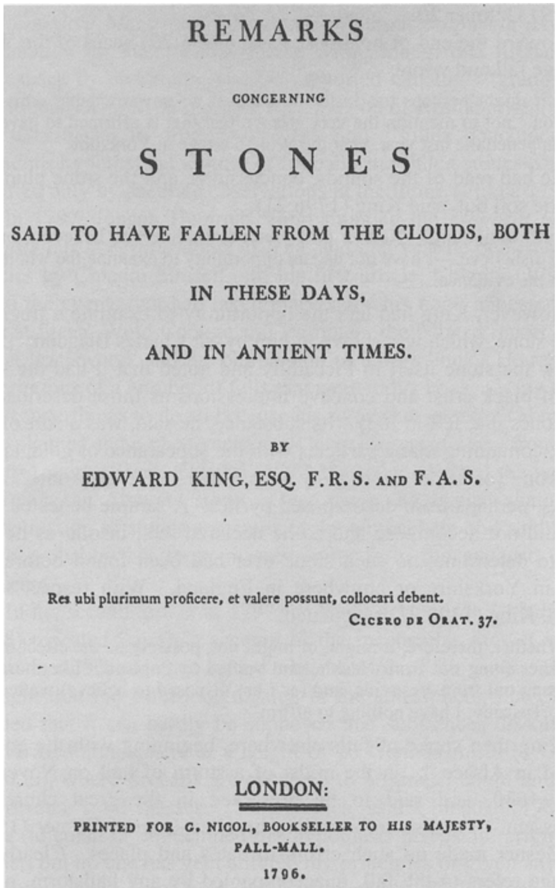
Fig. 12. Engraving of the Wold Cottage stone made for Captain Topham's handbill. He said the stone was about 70 cm in longest dimension. (Item No. 4 from Figure 1, *Gentlemen's Magazine*, July 1797.)

There, Sir Joseph Banks saw the stone and acquired a sample, quite likely from Captain Topham himself. In 1797, Topham published the text of his handbill and the engraving of the stone (Fig. 12) in *Gentlemen's Magazine*. Two years later, he erected a brick monument over the site of fall and planted trees around it. Today, with the trees long gone, the weathered inscription still tells us that

> On this spot, on December 13, 1795, there fell from the atmosphere an extraordinary stone; 28 inches broad, 30 inches long, and weighing 56 pounds; the column in memory of it was erected by EDWARD TOPHAM, 1799.

Topham's column may have been the first monument to be erected at a meteorite site of fall, but it is not the only one. In the late nineteenth century, an obelisk was raised in the arid interior of Bahia, Brazil, at the place where the large Bendegó iron had been discovered in 1784, and, as we noted above, in 1980 a large disk of cast iron was mounted at the find site of the Pallas iron on the high ridge of Mt. Bolshoi Emir in Siberia.

In 1804, Topham sold the stone to the mineralogist James Sowerby (1752–1822) for display in Sowerby's Museum in London. To Sowerby, the stone's most remarkable component was its native iron, which made a unique addition to the minerals of Britain, especially, he said, since it had fallen there like "Phaeton from heaven." Sowerby opened volume 2 of his *British Mineralogy* (1804:1*)[6] with a full description of the Wold Cottage stone under the heading: Ferrum Nativum, Meteoric Iron. In 1835, the Sowerby family put up the stone for sale, and a subscription was raised to purchase it for the British Museum of Natural History in London. In 1995 British meteoriticists held a symposium in recognition of the 200th anniversary of the fall. Wold Cottage is the largest meteorite to have fallen in the British Isles and ranks second only to the great stone of Ensisheim in all of Europe.



REMARKS

CONCERNING

STONES

SAID TO HAVE FALLEN FROM THE CLOUDS, BOTH

IN THESE DAYS,

AND IN ANTIENT TIMES.

BY

EDWARD KING, ESQ. F. R. S. AND F. A. S.

Res ubi plurimum proficere, et valere possunt, collocari debent.
CICERO DE ORAT. 37.

LONDON:

PRINTED FOR G. NICOL, BOOKSELLER TO HIS MAJESTY,
PALL-MALL.
1796.

Fig. 13. Title page of Edward Kings's book of 1796, the first treatise on meteorites to be published in English. (Courtesy of the Smithsonian Institution Libraries.)

EDWARD KING ON FALLEN STONES, 1796

In 1796, Edward King (1735–1807), a Fellow of the Royal Society, privately published a 34-page book titled *Remarks concerning Stones said to have fallen from the Clouds, both in these days and in antient Times* (Fig. 13). This was the first treatise on meteorites to appear in English. In eighteenth-century fashion, King composed a long subtitle that today would serve almost as an abstract:

> An Attempt to account for the Production of a Shower of Stones, that fell in Tuscany, on the 16th of June, 1794: and to shew that there are Traces of similar Events having taken place, in the highest Ages of Antiquity. In the course of which Detail is also inserted, an Account of an extraordinary Hailstone, that fell, with many others, in Cornwall, on the 20th of October, 1791.

King opened with a description of the shower of stones at Siena based on the "extraordinarily detailed account" by Professor Soldani, a translation of which he had received from Sir Charles Blagden (1748–1820), the secretary of the Royal Society. He reported Soldani's view that the stones had no connection with Mt. Vesuvius but were generated in the air from mineral substances arisen "somehow or other" as exhalations from the Earth. However, King himself tended to favor William Hamilton's idea that the stones might have formed from Vesuvian ash, which, wrote King, being rich in pyrite and iron, rose to prodigious heights, caught fire, melted, exploded, and rained down as stones. To account for the puzzling fact that Mt. Vesuvius lay more than 200 miles southeast of Siena and the dark and menacing cloud from which the stones fell approached Siena from the north, King referred to Hamilton's suggestion that a high wind might have wafted the ash northward past Siena until it met an opposite draft, turned south again, and precipitated stones over the city.[5]

Soldani's descriptions and engravings persuaded King that the stones were imperfect pyramids and parallelpipeds that had failed to completely crystallize due to the rapidity of their consolidation in the cloud. He saw their surface indentations as dents made by collisions with one another while the stones were still warm and plastic. King drew an analogy between the formation of these stones in fiery clouds with the instant consolidation of hailstones in frigid clouds (an idea touched upon by Hamilton) and compared the Siena fall with dramatic hailstorms that had occurred in England and France. The one illustration in his book is of a glass model of a half-ounce hailstone with four smaller ones inside it that fell in Cornwall on October 20, 1791.

Toward the end of his book, King (1796:20) mentioned the Wold Cottage fall almost as an afterthought:

> . . . it might perhaps too justly be deemed an unwarrantable omission . . . not to mention the very strange fact that is affirmed to have happened the last year, near the Wold Cottage in Yorkshire.

He had read of the sounds, concussions, and the stone plunging into the soil but, said King (1796:21):

> I affirm nothing. Neither do I pretend absolutely to believe; or to disbelieve. I have not had an opportunity to examine the whole of the evidence.

However, King had had the opportunity to examine a fragment of the stone, which was shown to him by Sir Charles Blagden. Later, he saw the stone itself in Piccadilly and noted that it had the same sort of black crust and concave impressions as those described on the stones that fell in Italy. Its substance, he said, was a sort of grit stone, containing many particles with the appearance of gold, silver, and iron (or rather more truly of pyrites). He also noted rusty specks, perhaps from decomposed pyrites. A sample he tested with acid did not decompose and so he declared that, insofar as he was able to determine, no such stone ever had been found before this time in Yorkshire or anywhere in England. With respect to its origin, King (1796:22) concluded:

> Whether, therefore, it might, or might not, possibly be the effect of ashes flung out from Heckla [in Iceland], and wafted to England: like those flung out from Vesuvius, and (as I am disposed to believe) wafted to Tuscany, I have nothing to affirm.

King then spoke of falls elsewhere, beginning with the one reported in Alsace "in the midst of a storm of hail on November 29th, 1630, and said to be preserved in the great church of Anzissem." For this information, he cited Conrad Gesner (1565), but Gesner made no such errors in dates and places. Clearly the passage refers to the fall, unaccompanied by any hailstorm, of the stone at Ensisheim on November 7, 1492. King reported (correctly) the falls at Eichstädt and Agram as described by Andreas Stütz in 1790 and then wrote (1796:26):

> Here I intended to have concluded all my observations. But a recent publication, which I knew not of, when these sheets were written, obliges me to add a few more pages. The new publication was "a very singular tract, published in 1794, at Riga, by Dr. Chladni."

Thus, King tells us that Chladni's book reached him in the summer of 1796 and he immediately publicized it in his own book. By then, two years had passed since Johann Blumenbach had sent a copy of it to Sir Joseph Banks along with a letter full of praises for it, only to have that copy set aside in silence. King thanked Sir Charles Blagden for bringing Soldani's book, Stütz' paper, and Chladni's book to his attention and providing him with English translations. King said he would not presume to interfere with Chladni's hypothesis of origin but that surely his facts deserve much attention. He then listed the falls in Chladni's book that he had not already described (and corrected his earlier mistakes respecting the Ensisheim fall, except that he dated it as 1493). King affirmed that he had preserved a faithful and honest record and would let the discerning weigh and judge. King himself believed that all of these events had been brought to pass on extraordinary occasions by the immediate "fiat of the Almighty."

At the end of his text, King (1796:32) felt obliged to add a postscript. He had just received from Sir Charles Blagden a present of one of the very small stones—an irregular quadrilateral pyramid—from Siena. The black crust was such as had been described before, but he found it to be quite remarkable for the appearance of a "sort of minute chequer work" formed by very fine white lines on the black surface. This may be the earliest description of the crazing seen on crusts of many stony meteorites. Examining the interior, he found an astonishing resemblance between this stone and the one said to have fallen in Yorkshire—both were of a gritty substance with metallic and pyritical grains, and spots where pyrites appeared to have been decomposed. Thus, as pointed out by Pillinger and Pillinger (1996), King published the first comparison between samples of the meteorite falls at Siena and Wold Cottage—a comparison commonly credited to Sir Joseph Banks.

His observations of the two stones, reminded King of the 1772 report of Fourgeroux, Cadet, and Lavoisier on the stone from Lucé, which also was pyramidal in form. King (1796: 34) ended his postscript and his book by remarking that:

> The academicians, indeed, thought it was a stone merely struck by lightning: but, since so many corresponding facts, in other places, so remote, and so unconnected with each other, and suggesting a more interesting idea, have now come to light; such sort of concurrent evidence . . . ought, surely, to be duly weighed: and may justly lead us to a different conclusion.

Responses to King's Book

Report of the Pettiswood Fall of 1779

On August 1, 1796, shortly after King's book appeared, Mr. William Bingley wrote to the editor of *Gentlemen's Magazine* (LXVI:726) that he possessed two pieces of a stone that fell with a loud peal of thunder in 1779 at Pettiswood, County Westmeath, Ireland. He said his whole village was enveloped with sulfurous fumes as a stone struck a wooden part of a harness and broke into three pieces. The affrighted horse fell to the Earth and two boys rushed to him in terror carrying fragments that Bingley found to be warm as milk just from the cow. The outsides were tinged a whitish brown and the insides were silver white.

Wrote Bingley (1796:727):

> I never related this narrative and shewed the concreted substance to any persons . . . who have ever treated this subject with the utmost ridicule that can be imagined, but such persons have been brought to acknowledge, that, at least, they had formed too hasty an opinion.

Bingley's fear of ridicule—the same motive that had inhibited Tata from reporting the Terra Nova di Sibari stone in 1755—had been overcome by the reports of King, Soldani, and Topham. (Although both stones are long lost, the one from Pettiswood is regarded as a genuine meteorite, but the Terra Nova di Sibari stone is considered doubtful, although its story has the ring of truth). Bingley offered his opinion, now that fallen stones had become respectable phenomena, that they consist of sands and other matter that are lifted upwards from lakes, rivers, and seashores by the powerful attraction of the clouds that rise from the waters, and are compacted in the sky. He felt that his own idea and Soldani's were similar except that he believed the substances rose as solids and Soldani favored exhalations. With respect to the Wold Cottage stone, Bingley (1796:728) wrote:

> I am not without hope, that, upon a farther investigation by the learned, my cake and Captain Topham's loaf will be found to have both been baked in the same stupendous oven, according to the due course of Nature.

An Anonymous Review

In short order, a five-page unsigned review of King's book appeared in *Gentlemen's Magazine* (1796:484). After recounting King's description of the events at Siena and Wold Cottage and remarking on fireballs, the reviewer (presumably the editor, Sylvanus Urban), revealed his attitude (1796:484):

> Much as we are disposed to give Mr. K. full credit for piety and religious zeal, we cannot agree with him in the propriety or probability of multiplying lying miracles on ordinary occasions; for we see not one extraordinary occasion among all that are here recited; nor is the

evidence of a few peasants or women to be admitted on those occasions.

The rest of the review consisted of scoffing remarks about King's ideas and the alleged circumstances of historical and recent falls, each of which the reviewer regarded as critically unexamined and not a little ridiculous. Despite decidedly mixed reviews, King's paper was widely read in England and on the continent. In 1797, an extract of it appeared in *Bibliothèque Britannique*, and Chladni (1797:20) spoke of it in Voight's *Magazin für das Neueste aus der Naturkunde*, where he said he was acquainted with it only through the English reviews.

NEWS RELATING TO METEORITES CRISSCROSSES EUROPE

Some sense of the time required for the dissemination of news at the turn of the 19th century is provided by the fact that more than two years had passed—from the spring of 1794 to the late summer of 1796—when King wrote the first remarks in English about Chladni's book. Chladni himself (1797:17) wrote that the first report of the Siena fall of June 1794 to be published in Germany was written by Herr Zóllner, head of the Church Council and an observer of meteors, whose article appeared in the *Berlin Monatschrift* of September 1796. Meanwhile, Hamilton's paragraph on the Siena fall in the February 1795 issue of the *Philosophical Transactions of the Royal Society* had reached Germany where one of its readers was Wilhelm Olbers at Bremen. Shortly thereafter, Olbers gave a lecture on the Siena fall at the Bremen Museum. In it he raised the question of whether the stones might possibly have been erupted by a volcano on the Moon. Olbers followed up on this idea by calculating the velocity required for a sizeable mass to escape from the Moon and fall to Earth. He concluded that the force was well within reason, but he published nothing on this subject until several years later.

Italian scholars led the way in publishing books and articles about meteorites in response to the Siena fall. William Hamilton and Edward King, in England, were the next in print. Then Chladni's book arrived in western Europe and the trickle of journal articles rose to a flood. In 1796, in the midst of the revolutionary wars, Marc-Auguste Pictet (1752–1835) in Geneva co-founded the *Bibliothèque Britannique* primarily to provide readers on the continent with French translations of scientific articles in English. From the first, Pictet published articles on meteorites, often with highly favorable editorial commentary. He also published negative viewpoints, so, in short order, the pages of *Bibliothèque Britannique* resounded with controversy. The letters exchanged in its pages, along with extracts of papers in English, French and German journals, provide a running commentary on the events and debates during the formative years of meteoritics.

In France, the *Journal de Physique, de Chimie, d'Histoire Naturelle et des Arts*, founded in Paris in 1777 by Jean-Claude Delamétherie (1743–1817), had published the analysis of the Lucé stone by Fourgeroux, Cadet, and Lavoisier that year in its second volume, thus establishing a certain editorial bias against the idea of fallen stones. In 1796, the journal began printing articles on falls, but Lamétherie postponed his own acceptance of fallen stones until 1803. Other French journals including *Annales de Chimie et de Physique*, founded in 1789, and the *Journal des Mines*, founded in1792, entered the fray in 1796.

In Germany, a paper on fireballs by Friedrich Carl Fulda (1774–1847) was the earliest article in German to seriously discuss Chladni's ideas. It appeared in volume 1 of Gmelin's *Göttingisches Journal der Naturwissenschaften* founded in 1796. Without proposing any new explanation for them, Fulda agreed with Chladni that fireballs are not caused by electricity and he supported Chladni's "grand idea" that fireballs as well as shooting stars may be of cosmic origin–which to Fulda meant in orbit around the Sun. In 1799 his article was extracted in the *Philosophical Magazine* in England. Fulda concluded that Chladni's hypothetical linking of fireballs and fallen stones could be justified only by accurate observations to be made in the future.

In 1797, Johann Heinrich Voigt founded the *Magazin für das Neueste aus der Naturkunde* in Jena, and that year he published two articles by Chladni himself. In his first article, Chladni (1797:17) listed the events that had taken place since his book appeared—the falls at Siena and Wold Cottage, the belated reports of the falls at Pettiswood and Barbotan, and the publication of King's book. He repeated descriptions of a number of falls that were in his own book, saying he felt it not superfluous to do so because his somewhat paradoxical method of explaining these phenomena may have prevented some from reading that work. Here, Chladni (1797:25) included Troili's book on the Albareto stone. Once again, he argued against the consolidation of stones and irons in the atmosphere and said it was more probable that these masses come from the expanse of the universe.

In his second article in 1797 for Voigt's *Magazin*, Chladni (1798b) repeated Baudin's account of the spectacular shower at Barbotan in 1790 and then added observations of his own. Baudin thought that the stones aggregated in the atmosphere, but Chladni argued that it can hardly be supposed that substances dissolved in the rarified atmosphere at a height of 20 German miles (1 G. M. = 7420 m) where fireballs are observed to originate, could unite into monstrous, solid masses. Some critics, said Chladni (1798:230), have ridiculed or condemned my hypothesis of cosmic origin altogether, but no one has yet confuted my principles or given any other explanation that accords so well with the facts. Chladni added that he could name several naturalists who had told him they agreed with the essential parts of his hypothesis but he felt it improper to name them without their express permission.

Chladni then replied to one of the strongest objections being raised to his assertion of cosmic origin: namely that a mass striking from such a prodigious height must sink not to a depth of a few feet but to the very center of the Earth. Chladni (1798:230) explained that the falling masses are not solid, but consist of soft, elastic fluids, which, being expanded by the heat to monstrous globular forms, are then supported by the atmosphere and lose the greater part of their gravity. He added that such soft, tough masses, falling obliquely, would not, in general, sink far into the Earth. This idea of Chladni's was in gross error; the falling bodies are, in fact, solid and, except for those massive enough to blast open impact craters, they make relatively soft landings after undergoing frictional deceleration in the atmosphere.

Chladni ended with a suggestion, he said was made to him by a colleague, that two or more astronomers, residing at some distance from one another, might agree to observe meteors in the same part of the sky, noting the time and apparent course of their appearance. Differences in meridians, and, from these, the real heights and directions of meteors, might be calculated. This plan, which delighted Lichtenberg, was carried out in September and October of 1798 by two of his students, Heinrich Wilhelm Brandes (1777–1834) and Johann Friedrich Benzenberg (1777–1846). They occupied opposite ends of a baseline 8.79 kilometers long stretching northward from Lichtenberg's garden cottage to a site in Clausberg. During their first three nights of observations they already realized they must use a longer baseline because the meteor region of the sky had proved to be markedly higher than the one German mile (7.4 km), which was widely accepted, at that time, as the height of the atmosphere. They saw that it was closer to the 20 German miles (148 km) favored by Chladni and a few other investigators.

Benzenberg and Brandes lengthened their baseline to 15.61 kilometers and continued their observations, on clear nights, through October. In all, they observed 402 meteors, of which 22 were simultaneous. From their data, they concluded that visible meteors occur at heights between 26 and 170 km, and they move at velocities of 29 to 44 kilometers per second (Czegka 2000). Their range included today's so-called "meteor region" at heights of 60 to 100 kilometers, toward which networks of synchronized cameras are tilted to photograph the night skies. Current measurements indicate the average velocity of meteors to be about 30 km/s. In retrospect, the lengthened baseline used by Benzenberg and Brandes still was much too short but they had made an impressive beginning to systematic meteor studies.

On November 3, 1798, Lichtenberg wrote to Benzenberg praising his experiment for showing that meteors do not originate within the atmosphere. On the same day, Lichtenberg added a postscript in a separate letter saying: "God forbid that such fiery bodies ever shall strike our Earth while flying at 5 miles per second. At least, I hope nothing like that ever shall fall on my head" (Joost and Shöne 1992, 4: 796.)

Years later, Chladni (1819:7) recalled that Lichtenberg at first did not like his book; he said it made him feel as if he had been hit on the head with one of Chladni's stones. Among Lichtenberg's writings, the quotation cited above from his postscript of November 3, 1798, is the closest approximation to what Chladni reported. However, Lichtenberg's praise for Benzenberg for having shown that meteors clearly originate above the atmosphere, was highly favorable to Chladni's hypothesis. In fact, Chladni (1819:10) listed Lichtenberg, as well as Olbers, Franz Xaver von Zach (1754–1832), and Abraham Gottlob Werner (1749–1817) among the earliest German scholars who accepted his hypothesis of fallen bodies. No doubt he would gladly have added Johann Blumenbach if he had known that Blumenbach had sent a copy of his book, along with an enthusiastic recommendation of it, to Sir Joseph Banks in 1794.

We have seen that fallen stones entered English literature with favorable articles by Hamilton in 1795 and King and Bingley in 1796, followed by a negative response in *Gentlemen's Magazine*. By that summer the news of the Wold Cottage fall was spreading just as King reported receiving Chladni's book. The lead paper in volume 2 of the *Philosophical Magazine*, founded in 1798 by Alexander Tilloch (1759–1825), was a concise 8-page outline of Chladni's book. Presumably, this article was written by the editor-in-chief Tilloch himself. The December 1798 and January 1799 issues of the *Philosophical Magazine* carried translations with commentary of the two articles by Chladni that had appeared in Voight's *Magazin* in 1797.

STONES KEPT FALLING

Portugal, 1796

In 1797 the English author Robert Southey (1774–1843), who one day would become Poet Laureate of England, published a book of 30 letters written on his recent travels in Spain and Portugal. He opened Letter No. 21 (p. 355) with the following disclaimer:

> A phenomenon has occurred here within these few days, which we sometimes find mentioned in history, and always disbelieve. I shall make no comment on the account, but give you an authentic copy of the deposition of the witnesses before a magistrate.

The deposition described the fall of a 10-pound stone near Évora, in Portugal, at 2:00 P.M. on February 19, 1796. Two reports were heard, similar to those of explosions in mines, followed by a great rumbling that lasted about two minutes. The sky was clear to the horizon, with no cloud in sight. One man heard a heavy body fall near him and found a stone the color of lead sunk into the ground, still warm. Southey, who was unaware of the falls at Siena and Wold Cottage, felt compelled to adopt his non-committal attitude toward the story, but his report proved to be well-timed. Appearing within a year of King's book, Southey's account brought to English readers fresh evidence of fallen stones from one of their much-admired "Lake Poets."[7]

Mulletiwu, 1795; Bjelaja Zerkov, 1796; Salles, 1798

Two additional falls took place in far off lands—Mulletiwu, Ceylon, at 8:00 A.M. on April 13th, 1795, and Bjelaja Zerkov in southern Russia on January 15, 1796—but they were not publicized at the time. Nor was there any account published until 1802 of a shower of stones at Salles in France's Rhone Valley at 6:00 P.M. on March 12, 1798.

Benares, India, 1798

A dazzling ball of fire exploded across a serene evening sky near Benares, India, at 8 P.M. on December 19, 1798, heralding a large shower of stones. Early in 1799, Sir Joseph Banks in London received a letter from John Lloyd Williams (about 1765–1838) in India describing the fireball and the appearance of the stones. All of them, he said, had hard black crusts like varnish or bitumen and whitish, gritty interiors with many small spherical bodies interspersed with bright shining grains of metal or pyrite. Williams (in Howard 1802: 179) concluded:

> I shall only observe, that it is well known there are no volcanoes on the continent of India; and, as far as I can learn, no stones have been met with in the earth, in that part of the world, which bear the smallest resemblance to those above described.

On reading the letter, Sir Joseph was struck by the apparent similarities between the Benares stones and the samples he had obtained from the falls at Siena and Wold Cottage. Judging that it was time for serious scientific investigations, he handed his two samples to the accomplished young chemist, Edward C. Howard (1774–1816) and asked him to analyze them. In December 1800, Banks presented the Copley Medal, the Royal Society's highest honor, to Howard for his discovery of the fulminate of mercury. In his presentation speech, Banks made it clear that he believed a new field of research was opening (Sears 1975: 218):

> Mr. Howard . . . is now employed in the analysis of certain stones, generations in the air by fiery meteors, the component parts of which will probably open a new field of speculation and discussion to mineralogists as well as to meteorologists.

CHEMISTRY AND CONTROVERSY: 1800–1803

Previous Chemical Analyses of Meteorites

Preparing for the task that Sir Joseph Banks had proposed to him, Howard combed the literature. He read Chladni's book, King's book, and numerous journal articles and found that only three chemical analyses had previously been performed on bodies of the type that Chladni had listed as fallen from the sky. These were the Lucé stone, the stone of Ensisheim, and the Mesón de Fierro from Argentina. In all three cases the analysts concluded that the bodies had not fallen from the sky.

Analysis of the Stone from Lucé, France, 1769

The analytical work on the stone from Lucé, performed in the spring of 1769 by the French chemists Fourgeroux, Cadet, and Lavoisier (1777), is discussed above. We will recall that these academicians concluded that it was a pyritiferous rock struck by lightning. And given the close resemblance to it of the stone from Nicorps in the Cotentin, they suggested that lightning may strike preferentially on pyritiferous rocks.

Analysis of the Mesón de Fierro, Argentina, 1799

In an effort to better understand the problem of "native irons," Joséf-Louis Proust (1754–1826), the French chemist who was then serving as director of the chemistry laboratory of Charles IV at Madrid, analyzed a minute (0.5 ounce) sample of the Mesón de Fiero collected by don Rubin de Celis in 1783. Struck by its silvery luster and its malleability, Proust applied a quantitative analysis for nickel which had been described only two years earlier, in 1797, by Sigismund Friedrich Hermbstaedt (1760–1833) in Berlin. Proust (1799: 149) reported 10 wt% of nickel in the iron. Never before had such an alloy been known. Proust, who was not thinking of the mass as a meteorite, remarked that his findings left undecided whether such metals are the work of nature or artifice.

Analysis of the Stone of Ensisheim, 1800

In 1800, Charles Barthold, professor of chemistry at the recently established Ecole Centrale de l'Haut Rhin at Colmar, chipped off a large sample of the stone, which was then on display at the Bibliothèque National, and performed a bulk analysis. Barthold (1800:171) reported finding 42% silica, 17% alumina, 20% iron oxide, 2% chalk (CaO), and 2% sulfur. His were the first determinations of silica, magnesia, and lime to be made on any meteorite (Sears and Sears 1977: 29). From his results, Barthold concluded that the stone was a common secondary type of argillo-ferrugineous rock that could have washed down a mountainside in a torrential storm. He speculated that the glitter of pyrite had fooled the superstitious local people into claiming for it a miraculous origin. Barthold ridiculed the old story that the stone had fallen from the sky.

Edward C. Howard Assembles Samples for Analysis

In addition to the stones from Siena and Wold Cottage, given to him by Sir Joseph Banks, Howard obtained samples of two more fallen stones, one from Benares sent to him by John Lloyd Williams, and the one said to have fallen in 1753 near Tabor, Bohemia, from Charles Greville (1749–1809), the prominent British collector (and nephew to Sir William

Hamilton).[8] Greville had acquired the Tabor stone when he purchased the collection of the Baron Ignaz von Born (1742–1791) of Vienna. From Greville and the British Museum, Howard also obtained samples of three native irons: the Pallas iron from Siberia, the Mesón de Fierro from Argentina, and a mass called the "Bohemian iron" (the Steinbach stony-iron) which had been presented to von Born by the Bergakademie at Freiberg. In addition, the English chemist, Charles Hatchett (1765–1847), gave him a second sample of the Pallas iron and a specimen of iron found at Siratik in Senegal (Mali) in 1716. This piece had been brought to London in 1799 by General Charles O'Hara (about 1740–1802), former commander of the English garrison at Gorée Island offshore from Dakar.

Working with the French emigré mineralogist, Jacques-Louis the Comte de Bournon (1751–1825), who had fled to England from the Reign of Terror, Howard began the first series of chemical analyses designed to test the possibility that the stones and irons he investigated might well have fallen from the sky. Meanwhile, an astronomer discovered a new planet.

A New Planet: Between Mars and Jupiter

On the evening of January 1, 1801, the opening night of the 19th century, Giuseppe Piazzi (1746–1826), director of the Royal Observatory at Palermo, Sicily, observed a small, previously unmapped body against the background of the constellation Taurus. He assumed it was a very faint star. On the next evening he found it in a slightly different position and thought he had made an error. By the third night, it had moved again so he concluded it was not a star but a planet or a comet, although it had no coma or tail. Piazzi continued his measurements on the few clear nights during the next three weeks. In late January, he sent descriptions of the body to three colleagues, Barnaba Oriani (1752–1832) in Milan, Johann Elert Bode (1747–1826) in Berlin, and Franz Xavier von Zach (1754–1832), the astronomer to the Duke of Saxe-Gotha, giving them its apparent positions on January 3 and 23. He told them he was naming it "Ceres Ferdinandea" in honor of Ceres, the patron goddess of Sicily, and King Ferdinand IV, his own patron. Needless to say, the name soon was simplified to Ceres. By 1801 February 1, the body had moved by 3° of a geocentric arc. In April 1801, Piazzi sent his few additional measurements to Oriani, Bode, and Lalande in Paris. But by then the body was too close to the Sun to be seen again until September. In Germany, von Zach published the sparse data he had from Piazzi in the first issue of his *Monatliche Correspondenz* (von Zach 1801:279–283), where it was seen by the brilliant, young mathematician, Carl Friedrich Gauss (1777–1855) who later would become Director of the Astronomical Observatory at Göttingen. Gauss had devised a new method for calculating a planet's orbit from observations made in a very limited time period (Forbes 1971). It involved no suppositions regarding the assumed path of an orbit except that it must be a conic section. Gauss was delighted with the opportunity to apply his method to a problem as important as locating the orbit of Piazzi's new planet. In November 1801, he published his results showing that the body was orbiting the Sun in the wide space between Mars and Jupiter, and he predicted when and where it would become visible again. On December 31, 1801, von Zach rediscovered it within one-half of a degree of where Gauss said it would be. Wilhelm Olbers found it two nights later. Von Zach said he doubted if it would have been found again without Gauss's calculations. Eight years later, Gauss (in von Zach 1809:147–192) published his calculations for which he had adopted the inverse-square law of gravitational attraction and reduced his data by the method of least squares, which still is used for minimizing errors in all sciences.)

The "Titius-Bode Law" of Planetary Distances

Piazzi's discovery of Ceres caused great excitement among astronomers because it occurred in the wide space between Mars and Jupiter, where the "Titius-Bode law," indicated there should be a planet. This "law," which had dubious beginnings and never was shown to have any basis in celestial dynamics, finally has dwindled to a mere curiosity. However, in the late 18th century some astronomers took it very seriously.

The story begins in 1764, with the publication of a book, *Contemplation de la nature*, by the famed Swiss naturalist, Charles Bonnet (1720–1793). Bonnet described regularities in nature that must have been established by the Creator. He said nothing about planetary distances, but two years later, in 1766, Johann Daniel Titius (1729–1796), professor of mathematics at Wittenberg, published a German translation of Bonnet's book in which he took the liberty of inserting a paragraph of his own outlining the spacings between the Sun and each of its successive planets. Titius wrote that if one divides the distance from the Sun to Saturn into 100 units, then Mercury lies at 4 units, Venus at 4 + 3 = 7, Earth at 4 + 6 = 10, Mars at 4 + 12 = 16, there is an empty space at 4 + 24 = 28, Jupiter at 4 + 48 = 52, and Saturn at 4 + 96 = 100. What a wonderful relation, he exclaimed. However, neither in the text, nor in a note, nor on the title page did Titius indicate that he had authored this paragraph. Nor, it seems, did he alert Bonnet to its insertion in the German translation of his book. Not until 1772—the publication year of the second edition of his translation of Bonnet—did Titius switch this paragraph to an initialed footnote and add his name to the title page. In that same year, Bode read the passage and, without crediting it to either Bonnet or Titius, he added it as a footnote to the second edition of his own book *Anleitung zur Kenntniss des gestirnen Himmels*, as he readied it for the press. Not until twelve years later, in 1784, did Bode concede that he took the contents of his footnote from Titius's translation. He said the footnote came from Titius's second edition, but inasmuch as Bode's own second edition was off the press and in distribution in

January 1772, it seems most likely that he took it from Titius's first edition (Jaki 1972:136–138, note 11).

On March 13, 1781, William Herschel announced to the Royal Society his discovery of a new body he believed was a comet, although it lacked a coma and a tail. Within a short time, the body was shown to be in too circular an orbit for a comet so it must be a planet. The news sent shock waves through the astronomical community. Herschel had discovered a planet unknown in antiquity—one that doubled the expanse of the solar system. His new planet was twice as far from the Sun as Saturn! Herschel proposed to name it "Georgium Sidus" in honor of King George III. That name, simplified to "the Georgian planet," persisted in England for decades, but elsewhere it was called Uranus, a name suggested by Bode who recalled that in Graeco-Roman mythology Uranus was the father of Saturn, who was the father of Jupiter. After its discovery, astronomers found old records showing that Uranus had been sighted at least eleven times between 1690 and 1769 by observers who did not recognize it as a planet.

Bode (1784) pointed out that Uranus orbited the Sun at a distance of 18.9 units which was close to the 19.6 units predicted by the law. Later the distance was corrected to 19.2 units which is even closer. Uranus lent a new credibility to the rule that was becoming known as "Bode's law."

The discovery of Uranus prompted Franz von Zach to conduct a systematic search for a planet between Mars and Jupiter. In 1787, he began his own search but quickly realized such an effort would require the participation of several observers. A year later, he called a meeting at Gotha where the French astronomer J. J. Lalande proposed a cooperative undertaking in which colleagues would choose portions of the sky to search. This idea met with hearty approval but no action was taken until twelve years later, when six leading astronomers met in September 1800 at the Lilienthal Observatory, near Bremen, which the German astronomer Johann Hieronymous Schröter (1745–1816) had developed into one of the leading observatories of the world. At that meeting, the participants agreed to invite 24 astronomers to search one twenty-fourth of the band of sky along the zodiac (Jaki 1972). One of the astronomers was to be Giuseppi Piazzi at Palermo. But before his invitation arrived, Piazzi had discovered Ceres. Ceres fitted so nicely into place that Bode declared the law was fulfilled and the solar system was complete.

The Great Debates

While Howard and de Bournon worked diligently to characterize their samples, a storm of controversy erupted in the literature.

Guillaume DeLuc versus Marc-Auguste Pictet

In 1801, Pictet published in *Bibliothéque Britannique* a French translation of the extract of Chladni's book that had appeared in 1799 in the *Philosophical Magazine*. By way of introduction to the piece, Pictet (1801a:74) referred to a work of sublime fiction, a glory of French literature, in which the author Jacques Necker (1800, 2:34) asks his readers to imagine the miraculous arrival on our Earth of some inhabitants of one of the celestial spheres; for several moments we have permission to talk with them and try to understand them: what questions shall we ask them? In thus giving wings to his brilliant imagination, remarked Pictet, the author scarcely suspects that certain facts have been brought to light that lead philosophers of our time to regard it as possible that there do arrive on our Earth not some living beings from other planets but samples of the material of which these planets are composed. We submit to the judgement of our readers, declared Pictet, the observations of natural history that have led this German professor (Chladni) to this singular conclusion. We invite them to hold off from unfavorable prejudgements and to give to the ingenious interpretations made by this wise author all the attention that they seem to merit.

There followed the extract of Chladni's book after which Pictet remarked that whatever we may think of his hypothesis, this German savant has put forward a more plausible explanation than all those offered previously of the singular facts of falling stones; which are difficult to doubt when we consider the great number of such events attested to by authorities who are, for the most part, respectable.

One reader, Guillaume-Antoine DeLuc (1729–1812) of Geneva, did not see it that way. In a letter to Pictet, dated July 5, 1801, he vigorously protested the publication of Chladni's ideas in *Bibliothèque Britannique* and the editor's favorable treatment of them. Bodies simply do not fall from the sky, wrote DeLuc, persons only imagine such things when lightning bolts strike too close to them. If bodies were to fall, they certainly would not land at the surface but would penetrate deeply into the Earth and shatter into a thousand pieces. Nor, he declared, do bolts of lightning transform common rocks to those imagined to fall. "There was a time," wrote DeLuc (1801a:314), "when belemnite fossils were called lightning stones . . . that idea may seem very strange today but is no more so than the current hypothesis."

DeLuc believed that geologists should seek natural causes for curiosities such as the Pallas iron. He argued, quite reasonably, that each time one discovers that the appearance of an object cannot be reconciled with sane physics and good logic, one should suspend judgement and continue studying it until one learns to understand it. From Pallas's description of the Siberian mass as "porous as a rough sponge," DeLuc concluded that it clearly consisted of volcanic scoria, similar in many respects to ferruginous scorias observed in lavas of numerous active and extinct volcanoes. Its large size and isolated position did not impress him in the least. Huge blocks of granite are found lying on wide plains and rugged highlands at enormous distances from granite mountains, wrote DeLuc, as are scorias from the vents of volcanoes. But, exclaimed DeLuc (1801a:318), nobody yet has informed us that the isolated blocks of granite fell from the atmosphere!

DeLuc's explanation for the granite erratics had been put forward by his older, and more famous, brother, Jean-André DeLuc (1727–1817), who is credited by some historians (e.g., Taylor 1979:78) with introducing the term "geology" in its modern sense in 1788. Both DeLucs held that scientific ideas must conform with the laws of the Creator. Thus, in a series of letters, completed in 1798, in which Jean DeLuc set out geologic and historical proofs of the divine mission of Moses, he wrote that in the 5th period of Creation great subterranean caverns in the Earth collapsed, triggering violent outbursts of expansible fluids at depth. These generated enormous eruptions of basalt and projected high into the air huge blocks of granite, primordial rocks, and volcanics which came to rest on limey and sandy deposits on mountains, valleys, and plains where they are found today. In 1779, Horace-Bénédict de Saussure (1740–1799) had pointed out that the great flying blocks should have made craters where they plunged back to Earth—a point ignored by the DeLucs.

To Guillaume DeLuc, the supreme harmony of the universe required that all globes move through space in their assigned places. Thus, Chladni's idea was unthinkable that small bodies left over from the Creation might travel through infinite space until they enter the gravitational sphere of a large body, or, worse yet, that planets—and even whole systems of planets—could have been formed, destroyed, and formed again from the debris of previous ones. Those naturalists, wrote DeLuc (1801a:313):

> . . . who give free rein to their imagination on points of such importance, and who abandon their religious contemplation of the works of the Creator, do not reflect on all the evil that they produce in the moral world.

Shortly after DeLuc's broadside appeared, *Bibliothèque Britannique* published a letter from Pictet (1801b:415) describing a visit to Howard in his London laboratory. When Howard showed him the suite of four stones he was working on, Pictet was astonished by their similarities—all had black, vitreous crusts and light, grainy interiors scattered with pyrite and malleable grains of metallic iron. They were strikingly different from any familiar rocks of our globe. Pictet declared that he no longer could doubt the fact of their falls from the sky—whatever might be their mode of origin.

Opposition Mounts: Louis Bertrand and Eugène Patrin

The editors of *Bibliothèque Britannique* received two additional negative responses to their extract of Chladni's book. The first was from Louis Bertrand (1731–1812) of Geneva, the second from Eugène M. L. Patrin (1742–1815), a prominent and widely traveled French mineralogist then serving as director of the national manufacturing organization at St. Etienne.

Bertrand (1801a:433) declared that Chladni's hypothesis that fragments of other planets fall on the Earth had been well-refuted in a recent issue by G.-A. DeLuc. If, however, Chladni were to abandon that idea in favor of forming the bodies in the atmosphere from terrestrial exhalations, he must show how 336 quintals of iron, rising as vapors and displacing at least 358,400 cubic feet of air, would precipitate, when set aflame, as a mass with a volume of nearly 59 cubic feet. How could the iron escape oxidation in the fire? How could it fall as pure, malleable metal?

Bertrand was no more favorable to DeLuc's explanation of the widespread distribution of huge blocks. One can scarcely understand, he wrote, how subterranean fluids capable by their expansion of breaking up rocks and projecting their fragments everywhere, have traversed so many beds without disturbing them. The fluids would have had to explode from a prodigious number of points on the Earth to scatter the debris that is found in every single country of any extent. However, most of the superficial beds of the globe are intact and in a state where the sea left them, with the exception of those disturbed by volcanoes or the works of man.

With many naturalists of his time, Bertrand pictured dramatic exchanges in the distribution of continents and oceans due to periodic displacements of the Earth's center of gravity. He argued that currents of tremendous force set up in oceans would wash huge blocks down the slopes of submarine mountains and deposit them on the shores of new seas. In his view, blocks as large and heavy as the Pallas iron could be deposited on mountain tops in the next cycle.

Here we see that large iron meteorites, encountered far from any plausible sources, became an issue in debates over the origin of erratic boulders of granite and other rocks that were scattered over the countryside of northern Europe. Not until the late 1820s and 1830s would scientists begin to visualize erratics as debris deposited by an ice sheet of continental proportions. The concept of an Ice Age, promoted in 1837 by Louis Agassiz (1807–1873) in his own flamboyant style, sparked some of the fiercest controversies in the history of geology.

Eugène Patrin opposed both Chladni's hypothesis that bodies fall from the sky and DeLuc's claim that the Pallas iron is volcanic. Wrote Patrin (1801:205):

> The two opinions are equally inadmissable. That of Mr. G.-A. DeLuc is contradicted by the facts of which I have certain knowledge . . . that of Mr. Chladni presents enormous difficulties.

Patrin had seen the Pallas iron at the Imperial Academy of Sciences in St. Petersburg and been impressed by Pallas's report that the country rock at its find site included bands of ore assaying 70% of iron. Patrin concluded that a bolt of lightning on the iron ore had melted the mass and reduced it to metal.

On November 10th, before there was time for any response to Patrin's letter, Guillaume DeLuc wrote to

Bibliothèque Britannique referring to Pictet's "interesting article" in which he described his visit to Howard in his laboratory and expressed his certitude that the stones he saw there actually had fallen from the sky. Do Pictet's observations destroy my arguments of last July against such an origin? asked DeLuc (1801b:273). I propose to examine this question (to which his answer was "No!"). DeLuc blamed all the excitement about falling stones on the supposed fall at Wold Cottage in Yorkshire, which, he said, simply could not have taken place. In his opinion, too many savants had been willing to be taken in by the word of an ignorant laborer. The stone at Wold Cottage, DeLuc assured his readers, had reposed in tranquility for many centuries in the niche in the soil where it was found.

DeLuc then turned his attention to Bertrand's recent letter arguing that exotic rocks such as the Pallas iron were distributed over the land by violent currents in the displaced ocean. DeLuc opposed Bertrand's hypothesis mainly because of its consequences. He said that Bertrand, and many other scientists of his time, believed with Edmond Halley that the Earth has an empty space at its center, partially occupied by a magnetic globe. Shifts in the position of that interior magnet would change the Earth's center of gravity and wreak vast changes in the distribution of lands and seas. Bertrand, he said, called upon close encounters of a long-period comet to nudge the magnetic core aside. DeLuc was horrified (1801b: 394):

> At the moment of the displacement, which Mr. B. contemplates without embarrassment, the sea with the greatest violence and accelerating velocity will sweep away the people and all living beings from the Earth. They all will perish. How can they escape that sudden invasion of the sea? But afterward the continents will be renewed! What a sad renewal! . . . We rely upon the Divine Providence for the preservation of His work. His ways are more certain and more efficacious than the thoughts of men.

This attack brought forth an irate letter from Bertrand (1801b:432) who printed the above paragraph by DeLuc next to a paragraph from his own book, in which he specifically addressed the problem of how to avoid the destruction of people and other living things during the translation of the ocean. If the seas are large, he wrote, the globe is much larger, and the oceans will principally flow from one hemisphere to the other through the profoundly deep valleys between them, such as the beds of the Atlantic and Pacific Oceans. He pictured the waters rushing from pole to pole on either side of the Americas. And always there would be highlands inaccessible to the waters to serve as havens for inhabitants of the land (which seems to beg the question of erratics on high mountains.)

Suddenly, in the *Journal des Mines* of November 1801, DeLuc announced a change of mind about the origin of the Pallas iron. He had concluded that the iron mass from Siberia most likely was a product of an ancient and long-abandoned mining and smelting operation. Although Pallas had reported that there was no local knowledge of such things near the site, DeLuc observed that certain scorias at the summit of Mont Salève near Geneva give positive indications that ancient (Gallo-Roman) foundaries existed there, although no traces have been discovered and all memory of them are lost. On completing his defense of this mode of origin, DeLuc remarked that if no sign of workings ever are found on the mountain in Siberia he will return to his theory of a volcanic origin of the mass. DeLuc wrote (1801c:220):

> I regard, at present, the question as perfectly settled. This mass that has given rise to so many hypotheses, and which has been considered to be native iron, is very simply, without any doubt, a product of abandoned exploitations of the mine near the site where it was found.

Analyses by Edward C. Howard and Jacques-Louis de Bournon: 1802

The situation in 1802 was aptly described by Louis-Nicholas Vauquelin (1763–1829), the French chemist, who wrote (1802a:308):

> While all Europe resounded with the reports of stones fallen from the sky, while savants, divided in opinion on this subject, were forming hypotheses to explain the origin of them, each according to his own viewpoint, Mr. Edward Howard, an able English chemist, was pursuing in silence the only route which could lead to a solution of the problems.

De Bournon noted that each of their stones had four main components: "curious globules," martial pyrites, grains of malleable iron, and fine-grained earthy matrix. Using a magnifying glass he performed the extraordinarily difficult task of separating each of these components so that Howard could analyze them individually. For the first time on any meteorites, Howard applied the alkali fusion technique to analyze the silicates (Sears and Sears 1977:30). The stones proved to be strikingly similar to each other in mineralogy and chemical composition, but were different in several respects from any known rocks of the Earth's crust.

Today we recognize de Bournon's "curious globules" as chondrules (little grains), named as such in 1869 by Gustav Rose (1798–1873) at the Mineralogical Museum of Humboldt University in Berlin. Howard found that the reddish yellow iron sulfide ("martial pyrites") differed from all known sulfides. It was nonmagnetic and more iron-rich than pyrite but Howard found it impossible to extract a pure sample. Not until the 1860s was this mineral shown to be stoichiometric iron sulfide (FeS), a new species virtually limited to meteorites. In 1863, at the urging of Wilhelm Karl Haidinger (1795–1871) in Vienna, Rose named this mineral, "troilite," in honor of Domenico Troili who, as noted above, had first noted this brassy mineral in the Albareto stone in 1766. Even after its composition was known, disputes on the crystallography and occurrence of troilite continued into the 20th century.

By applying the technique used by Proust, Howard confirmed Proust's value of 10 wt% Ni in the iron of Mesón de Fierro from Argentina, and he measured several percent of nickel in the three other irons and in the metal grains of the four stones. The presence of nickel decisively linked the stones with the irons and set “fallen bodies” apart from all known rocks and all manufactured metals. De Bournon (1802a:208) described the transparent, yellowish-green substance in the Pallas iron as similar to peridot (gem olivine); Howard’s analyses confirmed its identity. Chladni (1794:40) had struck the mark when he called it olivine before he ever saw a sample.

Howard listed his results on each portion of the stones he analyzed. After separating out the spherical grains, metal grains, and pyrites, the matrix materials approximated: 48% silica, 18% magnesia, and 34% oxide of iron. Howard (1802: 198) discussed the marked differences between his results on the four stones and those obtained by the academicians on the Lucé stone in 1769 and by Barthold on the Ensisheim stone in 1800. In both cases the chemists analyzed bulk samples in which they detected no nickel. Howard believed both would have found nickel if they had analyzed the metal fractions separately. The academicians (Fourgeroux *et al*. 1777) had reported 55.5% of “vitrifiable earths” without attempting to distinguish between silica and magnesia. Barthold had reported 42% silica, 20% iron oxide, 17% alumina, 14% MgO, 2% chalk (CaO), and 2% sulfur. Howard had found neither alumina nor chalk, but he suggested that if Barthold’s alumina should prove to be silica, their results would be in closer agreement. After reading Howard’s report, the French chemist Antoine de Fourcroy (1755–1809) analyzed an 11 kg sample of the Ensisheim stone and reported 56% SiO_2, 30% iron oxide,12% magnesia, 2.4% Ni, 3.5% S and 1.4% CaO (Fourcroy 1803:303). Fourcroy detected no alumina, so if Barthold’s alumina were added to his silica, his total of 59% silica would be closer to Fourcroy’s 56%, but both would be higher than Howard’s 48% of SiO_2.

Howard (1802:201) passed an electric discharge over a freshly fractured surface of a stone from Benares in an attempt to form a black crust on it. The stone was rendered luminous in the dark for a quarter of an hour, and the trace of the “electric fluid” turned black. He lay no stress on this because many substances become luminous by electricity. However, we now mark this as the first observation of thermoluminescence in a meteorite.

Howard (1802:211) summed up their findings on the stones:

> They all have pyrites of a peculiar character. They all have a coating of black oxide of iron. They all contain an alloy of iron and nickel. And the earths which serve them as a sort of connecting medium, correspond in their nature, and nearly in their proportions.

Fortunately for the founding of meteoritics, all of the four stones examined by Howard and de Bournon were ordinary chondrites. To Howard, their results, coupled with reports of witnesses to their falls, removed all doubt as to the descent of these stony substances and to the irons as well. To disbelieve on the mere ground of incomprehensibility, he said, would be to dispute most of the works of nature. Howard added that it is not necessary to further defend the fact of falls to those of impartial judgement, but is useless to argue against those who do not wish to believe in them.

Attempts to reconcile these occurrences with known principles of philosophy already were abundant, wrote Howard (1802:200):

> It is, however, remarkable that Dr. Chladni, who seems to have indulged in these speculations with most success, should have connected the descent of fallen stones with meteors . . . and that the descent of the stones near Benares, should have been immediately accompanied with a meteor.

Howard (1802:212) concluded with two questions:

> 1st. Have not all fallen stones, and what are called native irons, the same origin?
> 2ndly. Are all, or any, the produce of the bodies of meteors?

Howard’s paper introduced hard science into the controversy, and, as argued by Sears (1975:223), it was the single most important factor in bringing about wide acceptance of fallen stones. It is interesting to learn, therefore, that his feelings about them were much more positive than he stated in the text. Sears (1976:135) reported that a large number of alterations were made in the manuscript before its publication—some probably by Howard himself and some by Edward W. Gray, the secretary of the Royal Society. Many of the alterations tempered the style so that assertions became possibilities. For example, the title which had read “Substances which have at different times fallen” was changed to “Substances, which at different Times are said to have fallen” (Sears 1976:135).

Today, the Siena, Wold Cottage, Tabor, and Benares stones are classified, respectively, as LL5, L6, H5, and LL6 chondrites, Krasnojarsk (the Pallas iron) is taken as the type specimen of pallasites, and Steinbach (the Bohemian iron) is classed as an anomalous IVA stony-iron. Although the Mesón de Fierro itself lies lost in the Chaco, the abundant irons collected at Campo del Cielo, Argentina, are fragments of a IAB coarse octahedrite. The Siratik iron in which Howard reported 5–6% Ni presents a problem: two specimens labeled Siratik in the British Museum that would have been available to Howard consist of cast iron with $<0.1\%$ nickel. In other European museums, certain samples labeled Siratik from the same source area, are fragments of a hexahedrite containing about 5% nickel (Buchwald 1975, III:1135). Did de Bournon fail to recognize cast iron? Did Howard report 5% Ni in a sample of cast iron? (Surely not!) Or, more likely, did they analyze a hexahedrite fragment that is not now in the British Museum?

Howard read his report at three successive meetings of the Royal Society, on February 25, March 4, and March 11, 1802. The sessions were well attended partly because his presentations were interspersed with new observations on the planet Ceres. Howard's manuscript, which included sections authored separately by de Bournon and a letter on the Benares fall by John Lloyd Williams, was published in the February 1802 issue of *Philosophical Transactions of the Royal Society.* In short order the Howard-de Bournon paper received much attention in England and France. The March issue of the *Philosophical Magazine* published an extract of it. Pictet himself attended the Royal Society meetings and published his account in the May issue of *Bibliothèque Britannique*. The following autumn, a 30-page extract signed by Citizen Tonnellier (Louis-Auguste Tonnelier-Breteuil 1730–1807), curator of minerals at the Ecole des Mines in Paris and a former president of the academy, appeared in the October–November 1802 issue of the *Journal des Mines*. Extracts also appeared in both the *Journal de Physique, de Chimie, et d'Histoire Naturelle* and *Annales de Chimie et de Physique.*

Significance of the Chemical Studies

The chemical and mineralogical work of Howard and de Bournon placed meteorite studies on a firm scientific basis and set new directions for laboratory procedures. Subsequently all analysts separated fallen stones into their main components and performed quantitative determinations of nickel on the metals. Most of them also adopted the alkali fusion method of analyzing silicates.

In the spring of 1802, Howard visited Paris and learned that Vauquelin had analyzed stones from the Barbotan and Siena showers. His results were similar to Howard's, and Howard urged him to publish them. In October 1802, Pictet presented Howard's results to the National Institute of Sciences and Arts (into which the Royal Academy of Sciences had been transformed during the Revolution), and four months later, on February 10, 1803, Fourcroy presented Vauquelin's results to the institute. These chemical data persuaded several leading members that the fallen bodies do indeed constitute a separate type of matter that must originate outside the Earth.

A Second Small Planet: Between Mars and Jupiter

On March 28, 1802, Wilhelm Olbers was searching for Ceres when he discovered a second small body in orbit between Mars and Jupiter. He proposed to name it "Pallas," but Bode would not hear of it. By then, Bode held prestigious positions as both the director of the Berlin Observatory and the editor of the *Astronomisches Jahrbuch* he had founded. Bode would not accept two planets between Mars and Jupiter because that would upset Bode's law, which he held to be sacrosanct. Olbers suggested that the two small bodies might be fragments of a larger planet that had been destroyed by an internal explosion or a collision with a comet. He predicted that more pieces would be discovered. Bode continued to refer to Pallas as a comet while Olbers, Gauss, and others were calling it a planet. In 1802 Herschel proposed a new name, "asteroids," for small bodies that are neither stars, nor comets, nor standard planets. Some astronomers objected that "astrum" means "star" and there is nothing star-like about these bodies; they would have preferred, "planetoids," or "even cometoids". But "asteroids" was quickly adopted and is commonly used along with "minor planets."

Today, the Titius-Bode law is consigned to the history books. No theoretical justification for it has been found except for the wide space between Mars and Jupiter where perturbations by Jupiter's powerful gravitational field prevented the accretion of a large body and left that space almost empty. The asteroid belt may contain a million bodies at least one kilometer in diameter, but their total mass equals only about 2% that of Earth's Moon; and one-third of that is in Ceres.

Lunar Volcanic Origin: Laplace's Hypothesis?

In September 1802, Pierre-Simon Laplace (1749–1827) wrote to Franz von Zach raising the question of whether fallen stones might be ejecta from volcanoes on the Moon. Laplace raised this issue again in February 1803, following Fourcroy's presentation of Vauquelin's results to the institute. His question aroused much interest among the members. Siméon-Denis Poisson (1781–1840) began calculations to test it. Jean-Baptiste Biot (1774–1862) supported the idea with enthusiasm (Biot 1803a). In December, after news of "Laplace's hypothesis" reached Bremen, Wilhelm Olbers (1802:121) wrote to Carl Gauss:

> What say you to stones fallen from heaven, and Laplace's idea that perhaps they are the product of lunar volcanism? The possibility of a selenitic origin of these stones I suggested 7 years ago in a lecture here in the Museum on the shower of stones from Siena.

Olbers said that back in 1795 he had not taken a lunar origin seriously because he understood that Hamilton had seen similar rocks on Mt. Vesuvius. However, Olbers had calculated the lunar escape velocity and concluded that a vertical force of only about 7,800 to 8,000 feet per second would be required to project heavy bodies off the lunar surface. Such a force seemed well within that of the violent eruptions that were required to form the lunar craters. To Olbers, therefore, it appeared not altogether impossible that the stones, which so closely resembled each other but were unlike those of the Earth, had come from the Moon.

Olbers (1803a) finally published his lecture notes and calculations of 1795. While a lunar origin seemed possible, Olbers saw great difficulties with this idea. First, the forward motion of the Moon would require that, to fall on the Earth, the ejected bodies must assume elliptical orbits with perigees within the Earth's body or its atmosphere. Only a few fragments would follow such orbits while a great many more would circle the Earth as satellites; meanwhile, the Moon should dwindle in size from a constant loss of mass. Although Olbers was intrigued with the idea, he was far from asserting that the fallen stones had been projected from the Moon. It was the same with Laplace, who raised the question and discussed it, but never seriously proposed a lunar origin.

Olbers (1803b:289) discussed all the difficulties with a lunar source in a second letter to von Zach:

> It is much to be wished that the ingenious Chladni would favor us with a new edition of his celebrated essay on the mass of iron found in Siberia, as he no doubt would be able, from Benzenberg and Brandes' observations on fallen stars, Howard's chemical examination, and from various other documents, to make considerable additions to it.

It is interesting to learn that as early as 1803 a leading German astronomer was calling for a second edition of Chladni's book. Sixteen years would pass before Chladni issued his second book, *Über Feuer-Meteore* (1819), in which he compiled the extant information about the occurrences and physics of falls and the composition of meteorites.

Today, Olbers is generally credited (e.g., Burke 1986:61) as the first person to speculate that meteorites might be lunar volcanic ejecta, but we already have met with that idea in a letter from Guglielmo Thomson in Naples to Soldani, written in 1794.

The Debates Intensify

The Conversion of Saint-Amans

On March 30, 1802, Jean F. B. Saint-Amans (1748–1831), then a professor of natural history at Agen, sent an excited letter to *Bibliothèque Britannique*. Saint-Amans recounted the story of the fall at Agen (Barbotan) in 1790, his own demand for a notarized document, and the subsequent editorial by Berthelon that despaired of the popular belief in an impossible phenomenon. Saint-Amans (1802:87) wrote:

> Afterward, citizen, this event entirely faded from my memory; I had forgotten the meteor, the stones, and the deposition . . . [until] reading your description of the stones that were said to have fallen from the clouds, I remembered that along with the deposition I had received a sample of one of the stones from Agen. I ran to my cabinet and found that, by sheer chance, I had saved the sample; such was my surprise, I dare say my delight, when I saw in this sample a striking identity with those which you described: a shiny surface, grainy fracture, metallic grains in the interior! It is impossible not to be astonished with such a resemblance. This new observation . . . seems worthy of being communicated to you. [I find it] very remarkable that all the "fallen" stones . . . from different countries present exactly the same characteristics, and I remain convinced that, however absurd the allegation may have appeared . . . one must hurry up to ascertain the facts.

Saint-Amans soon was leaving for England and wished to know where he could see the stones being studied; he would bring along his own specimen for comparison.

Guillaume DeLuc versus Marc Pictet: Second Round

Immediately following Saint-Amans letter in the *Bibliothèque Britannique* was a four-page account by Pictet (1802:89) of Howard's paper in the *Philosophical Transactions of the Royal Society.* He reviewed the methods employed by Howard and de Bournon, and reported their results emphasizing the importance of Howard's discovery of nickel in the metals of both the irons and stones. Writing in a matter-of-fact tone as though he were reporting well-established facts, Pictet cited the nickel as evidence of an origin outside the Earth.

Guillaume DeLuc, who had attended Howard's final presentation to the Royal Society on March 11, 1802, read Pictet's summary with growing concern, which he voiced in an article that, by chance, was printed directly after Tonnellier's extract of Howard's paper in the *Journal des Mines*. DeLuc protested that he already had rebutted Chladni's ideas of rocks falling from space, had shown it to be inconceivable that large bodies can form in the atmosphere, or that ordinary rocks may be transformed to metal by lightning bolts—except in folk tales.

> Nothing is more common, declared DeLuc (1802:94) than stones or rocks, coarse-grained on fractured surfaces, of the type that so astonished M. Saint-Amans. Grits, sandstones, granites, all contain mineral particles that look like that; examples multiply when we consider volcanics.

DeLuc once more raised the issue of the Wold Cottage stone. Meteors always were said to occur in the form of luminous globes; how, then, he asked, could this angular, irregular stone of gray granite have fallen from a meteor? In any case, the supposed fall was attested to by a mere laborer. DeLuc did not doubt that the laborer believed his own story, but the reports of others in the area had convinced DeLuc that a sudden peal of thunder had occurred—as sometimes happens in December and January—and a bolt of lightning had struck a rock nearby impregnating it with a strong odor of sulfur and sending up chips of surface material all around the laborer. DeLuc attacked Edward King's conjecture that the stone might have formed from ash of Mt. Heckla—the impossibility, he said, was only too evident. Nothing falls from the sky, declared DeLuc: no pieces of planets, no thunder stones, no concretions of volcanic vapors. Nowhere in this paper does he mention Howard by name or allude to his analytical results.

Eugène Patrin Challenges Howard and de Bournon

In contrast to Saint-Amans, who willingly abandoned his earlier prejudices, Eugène Patrin responded to Howard's paper with seventeen pages of biting criticism in the June 1802 issue of the *Journal de Physique, de Chemie, et d'Histoire Naturelle*. His opening salvo set the tone (Patrin 1802:376):

> To present to the public marvelous facts is to be assured of pleasing the great majority of readers; to destroy the

> marvelous and to return events to the common order is not the way to be received so favorably; but the zealous love of science and nature demands that sacrifice.

Thus, in effect, Patrin began by challenging the motives and scientific integrity of Howard and de Bournon. There are some today, he said, who regard it as something juridically proven that there fall to Earth, from time to time, stony and metallic masses, some of which are of considerable size. Some believe they are the matter of fireballs; others regard them as pieces of other planets. Mr. Howard, a very competent English chemist, has accepted the reports of various witnesses that tend to prove the fall of these stones, but it is very important to note who all these persons are. Mr. Howard has declared that these stones have nothing in common with thunder, and that since we have learned of the identity of the phenomena of thunder and electricity, the idea of a thunderstone "is ridiculous." Nevertheless, if the reports of the witnesses can prove anything, it is that the stones in question are veritable thunderstones—of the sort that Howard himself has called ridiculous. Patrin composed the following list of seven facts (here severely abbreviated) cited by Howard and his own reflections upon them:

Fact 1. Howard reported that Mr. Southey provided a notarized document detailing the fall of a stone in Portugal on February 19, 1796. Patrin's response: I can only observe that reports of such marvels, even when juridically certified, especially in certain countries, are always doubtful.

Fact 2. Howard stated that the Abbé Bachelay had sent a stone to the Royal Academy that persons said they had seen fall on September 13, 1768. Patrin's response: the chemists of the Academy, including Lavoisier, analyzed it and said that it had not fallen from the sky, but was simply a pyrite-rich substance struck by lightning. This stone was much the same as a sample of rock covered with glassy blisters that was collected on the summit of Mt. Blanc in 1787 by the illustrious Horace-Bénédict de Saussuré, who concluded that it had been struck by lightning.

Fact 3. Howard described the large stone known as the "thunderstone of Ensisheim" that was said to have fallen in Alsace on November 7, 1492. Patrin's response: Professor Barthold at Colmar analyzed a sample and found it to be nothing else than a spheroidal concretion of the sort frequently found in beds of pyrite-rich argillite. Barthold concluded that the glitter of pyrite had fooled the superstitious populace into giving the stone a miraculous existence that was contrary to the first principles of physics.

Fact 4. Mr. Howard invoked the alleged fall of stones at the feet of men, women, and children after a series of detonations at Siena in 1794. Patrin's response: it is easy to see that this type of evidence is not to be relied upon; thousands of absurdities have been certified by thousands of witnesses of that sort. In simple truth, the stones of Siena were, like the one from Lucé analyzed by Lavoisier, pyrite-rich masses struck by lightning. Inasmuch as Howard's analyses bore no resemblance to that of the three French academicians, they are not to be relied on.

Fact 5. Howard described the fall of a 56-pound stone at Wold Cottage in Yorkshire and the many attestations by witnesses to the event. Patrin's response: Howard was taken in by the testimony of mere laborers. Lightning had struck a pyrite-rich concretion in the chalk beds of the area.

Fact 6. Howard described a supposed shower of stones containing pyrite and metal near Benares on the 19th of December, 1798. Patrin's response: Mr. John Lloyd Williams in his letter to Sir Joseph Banks (included in Howard's report) stated that neither he nor any persons he could name had actually seen stones fall. He relied on villagers at some distance from Benares. In addition, Howard passed an electric discharge over a sample from Benares and found that the trace of the electric fluid had turned black. Howard did not seem to realize that he had performed with his battery the same thing that lightning performed in the fields of Benares.

Fact 7. Howard analyzed a stone from Tabor, Bohemia, among his "fallen stones." Patrin's response: the celebrated mineralogist Ignaz von Born himself had written that the pyritiferous stone from Tabor was nothing extraordinary, although he noted that some credulous people claimed that it fell in the midst of thunderclaps on July 3, 1753. Here again, is a thunderstone of the sort that Howard himself has called ridiculous.

Before challenging Howard's chemical findings on isolated masses of iron, Patrin disputed the value of each of the mineralogical descriptions by de Bournon. In sum, he found nothing in these stones with black crusts and gray, gritty interiors scattered with metal, gray globules, and pyrite that set them apart from ordinary rocks. When he finally mentioned Howard's findings of nickel in the metals, Patrin declared that many minerals contain nickel, none of which are under the slightest suspicion of being related to meteors. Patrin (1802:393) concluded: ". . . the love of the marvelous is the most dangerous adversary of science."

De Bournon Takes up the Challenge

De Bournon (1802b:294) responded in high dudgeon. How could Patrin dismiss detailed analytical work on stones without ever seeing them or any others like them? If he had seen those he and Howard had worked on, Patrin would know they did not consist of pyrite but had very small amounts of pyrite scattered through them. Patrin did not approve of the witnesses Howard relied upon; he would prefer them to be educated people. So, perhaps, would we, said de Bournon, but stones fall mainly in the countryside and are observed by country people who provide descriptions of marked similarity. How did Patrin explain nickel in these stones and none in deposits of pyrite? If, as Patrin believed, lightning bolts had transformed veins of iron ore into the 1,600-pound mass of metal from Siberia and the 30,000-pound mass in Argentina, what bolts of lightning those would be! Patrin himself must love marvels! Patrin must choose whether he will claim that the lightning bolts changed part of the iron to nickel, or introduced nickel into the metal. Since issuing their report he and Howard had analyzed two more stones, those from Salles and Barbotan, and both were of the same kind as the four analyzed earlier. It was, de Bournon wrote, beyond the laws of chance to find, time after time, the same unusual type of stone where people have seen them fall—whatever the social rank of the witnesses.

The Concession of Eugène Patrin

In the December issue of *Journal de Physique, de Chemie, et d'Histoire Naturelle* Patrin (1803:392) conceded all points. He said that he regretted his previous attack on the proofs given for the fall of stony masses from flaming meteors. He had mounted his attack, he explained, because, independently of his respect for the savants who reported them, he had a great interest in seeing demonstrated with certainty a fact that would support his theory of volcanoes. He had founded his theory on his conviction that matters that nourish volcanoes and those that belch forth from them are furnished by the fluids of the atmosphere, which, after having circulated within the Earth's crust where they are modified and recombined, erupt as inflammable metallic and stony matters that produce all the phenomena of volcanism. Nothing could be more analogous to this than the theory that masses of inflammable stony and metallic matter form in the atmosphere and are accompanied by burning meteors as they fall.

Patrin said he was not at all surprised to see that solid matter held in solution in inflammable gases could recombine into masses of more or less considerable size. It certainly was not the possibility of this fact that Patrin had pretended to contest; on the contrary, he contested it only because he wished to see it confirmed, and he much regretted that he had not accepted the testimony of the eyewitnesses to this reality.

Now, wrote Patrin, the new proofs set forth by de Bournon left nothing to be desired. Patrin was gratified, he said, to have given this respected naturalist the occasion to authenticate more and more of these facts that are of such importance to our terrestrial sphere. Now, with his volcanic theory seemingly confirmed, no further objections to fallen stones were to be heard from Eugène Patrin.

Over the New Year, 1803–1804, *Journal des Mines* published a French translation by Eugène Couquebert of Chladni's book, *Ironmasses*.

NEW FALLS: FRESH EVIDENCE

The Fall at Salles, France, 1789: A Belated Report, 1803

In March 1803, Etienne Marie Gilbert, the Marquis de Drée (1760–1848), who was said to possess the finest mineral collection in France, wrote in great excitement to the National Institute that he had examined one more fallen stone. On a visit to Lyon in February 1802, de Drée had been told by Dr. Pétetin, president of the Medical Society of Lyon, of the fall of a stone that had occurred at 8:00 P.M. on June 17, 1798, at Salles, near Villefranche. Scarcely able to contain himself, de Drée asked to see a sample. The doctor promised to send him one if he could find it. Shortly thereafter, he received the stone and De Drée wrote: (1803a:372):

> I was struck with more than a grand surprise when I found in this stone a perfect identity with the samples I have of those from Benares and Wold Cottage; an identity not only manifested by the types of rock, and by their mineralogical composition, but also by the effects resulting from their movement in the fluid atmosphere!

In those years, person after person was experiencing the shock of recognition that led to confirmation of a phenomenon that was entirely new to science.

De Drée, 1803: The First Meteorite Classification

De Drée took a great interest in meteorites and immediately began to work out a classification of them based chiefly on their materials, as reported by Howard and Vauquelin, and the circumstances of their falls. He distinguished the following four classes (de Drée 1803b:410):

Class I: Stones consisting of similar materials that fell in serene weather without thunderstorms: Salles, Ensisheim, Barbotan, Benares, Wold Cottage.

Class II: Stones of the same materials as class I but which fell from enflamed clouds with lightning flashes with or without detonations: Siena, Tabor.

Class III: Masses mainly of malleable iron, of which the only observed fall occurred at Agram in Croatia after a fireball and an explosion followed by rumbling sounds.

Class IV: All masses for which the circumstances of fall are not verified and their compositions fall outside those of the first three classes or are uncertain: his list of about 20 included the irons found in Siberia, Argentina, and Senegal; stones from observed falls including Lucé, Eichstädt, and Portugal, and about a dozen historical accounts taken mainly from Chladni.

De Drée's attempt illustrates the importance given at that early time to the circumstances of falls as though they might have genetic significance. It also shows the immensity of the labors that lay ahead in efforts to understand meteorites and construct meaningful classifications of them.

The Fall at L'Aigle, France, 1803

On April 26, 1803, at one o'clock in an afternoon of clear skies, a fireball coursed northwestward out of a single high, gray cloud in the vicinity of L'Aigle in Normandy. After three violent detonations, nearly 3000 stones fell into the fields with loud hissing noises. Thunderous reverberations continued for

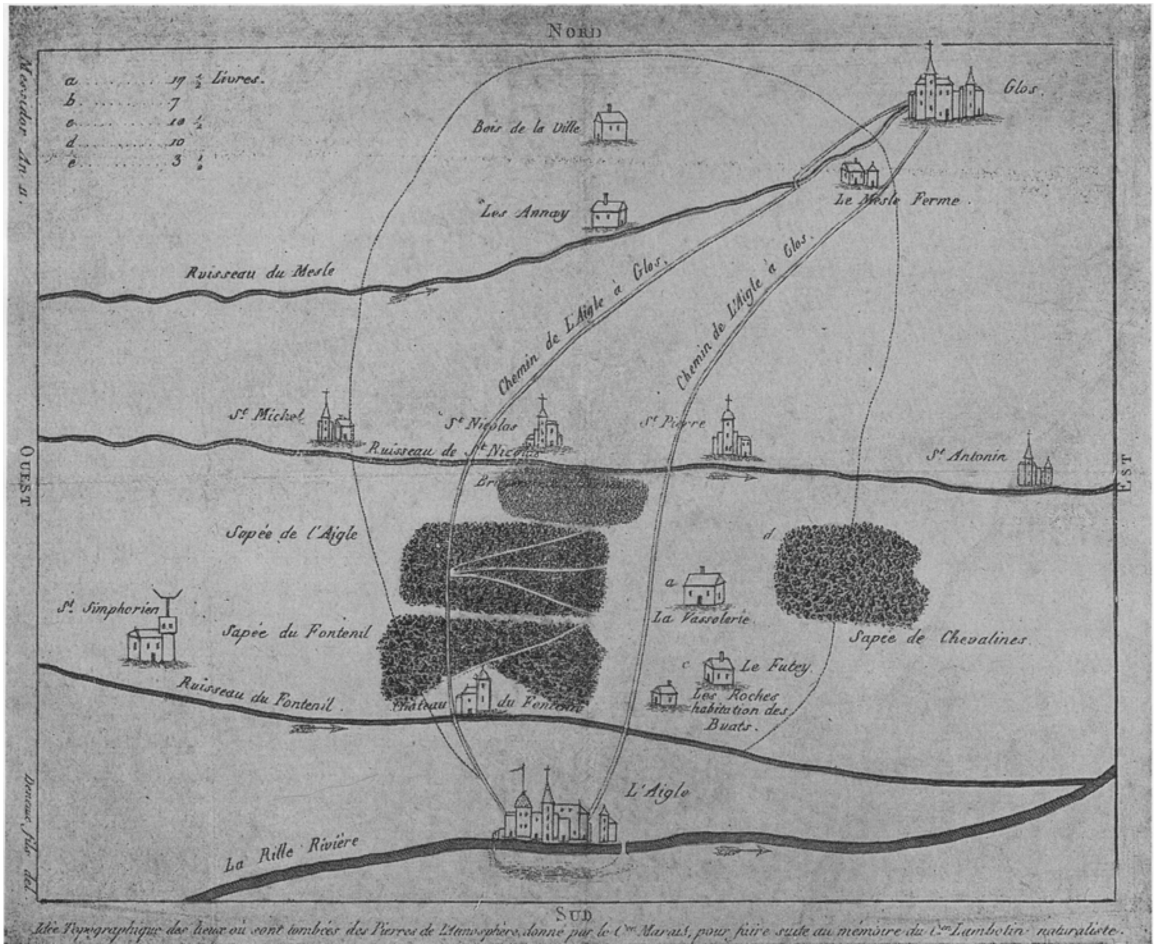


Fig. 14. Map of the L'Aigle area. The notation in the margin reads: "Topographic idea of the place where the stones fell from the atmosphere, drawn by Citizen Marais for inclusion with the memoir of Citizen Lambotin, naturalist." The dotted line outlines the area where stones were found. Notations at upper left key the locations and weights of 5 stones, ranging from 3 to 17 pounds. Dated Messidor, An XI (June 20–July 18, 1803), this was the first map to outline a strewn field. Unfortunately, the map was not published with Lambotin's memoir, which had appeared the previous month (Prairial). (From de Brébisson 1916; from the Paneth reprint collection, courtesy of the National Museum of Natural History, Smithsonian Institution.)

the next ten minutes. Affrighted persons who picked them up reported the stones to be very warm and smelling of sulfur. The stones were polygonal in shape, covered with black crusts, and ranged up to 17 pounds in weight. Fourcroy obtained stones and analyzed them in collaboration with Vauquelin. They found them to closely resemble all other fallen stones. On June 19 Fourcroy (1803:304) reported their results to the National Institute and declared that they favored Chladni's hypothesis of fallen stones.

A Report by Charles Lambotin

The first published account of the event appeared in the May–June issue of the *Journal de Physique, de Chemie, et d'Histoire Naturelle*. It was written by Citizen Charles Lambotin (1803), a student of mineralogy and dealer in natural history objects in Paris. Lambotin quoted from a letter written on May 3 by an eyewitness, one Citizen Marais of L'Aigle, to a friend who lived in the same house in Paris as Lambotin. The friend, M. Chateau, passed Marais' letter to Lambotin, urging him to bring this matter to the attention of the National Institute. Lambotin immediately wrote to L'Aigle for more information and commissioned a search for stones. Before the month was out, his agent reported that, despite the most zealous efforts, no more stones were to be found in the countryside. By then, however, Lambotin possessed a sufficient quantity to sell stones to all the great and small collectors in Paris.

In the month of Messidor An XI (June 19–July 18, 1803) Citizen Marais drew a sketch map of the L'Aigle district (Fig. 14) to be included in Lambotin's memoir. It shows a large, somewhat lopsided area, open-ended just north of L'Aigle, within which stones were found. This is the earliest map to represent a meteorite strewn field. Unfortunately, it was not included with Lambotin's memoir, which had been published the previous month. However, sixteen years later Lambotin's memoir, accompanied by Marais' map, was

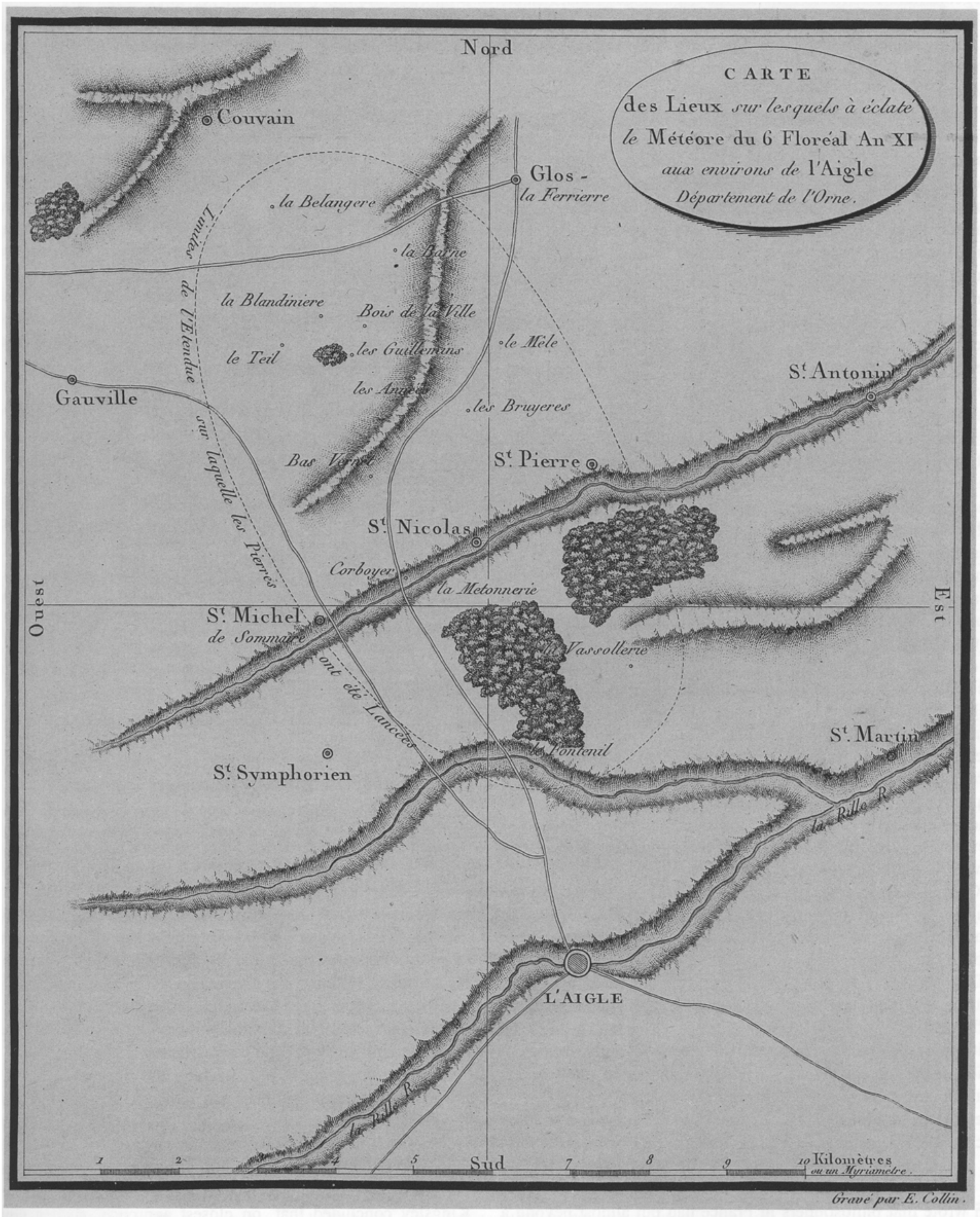


Fig. 15. "Map of the places over which the meteor exploded on 6 Floreal An XI (April 26, 1803) in the environs of L'Aigle, Department of Orne," by Jean-Baptiste Biot. The dashed line is labeled "Limits of the area in which the stones were flung down." Biot included a scale, which is lacking in Marais' map, and showed the strewn field as a closed ellipse. This map appeared in Biot's report to the National Institute of Sciences published in the month of Thermidor, An XI, (July 19–August 17, 1803). Thus, it is the earliest published map of a meteorite strewn field. (From Biot 1803b; from the Paneth reprint collection, courtesy of the National Museum of Natural History, Smithsonian Institution.)

inserted by the editor, Eugène Patrin himself, into the article on “Pierres Météoriques” in the first edition of the *Dictionnaire d‘Histoire Naturelle* (1816–1819). A century later, Marais’ map was rescued from obscurity by R. de Brébisson (1916) in his review of the fall at l’Aigle.

A Report by Jean-Baptiste Biot

Meanwhile, perhaps through the influence of Laplace who wished to test the likelihood of a source on the Moon (Burke 1986:54), Jean-Antoine Chaptal (1756–1832), minister of the interior, sent the young Biot to gather more data on the fireball trajectory and the extent of the fall. Carrying along a stone from the Barbotan fall of 1790, Biot left Paris on June 26 and approached L’Aigle by an indirect route, questioning people along the way, learning who had heard explosions from what direction, who had seen a fireball, how high and bright it appeared, which way it was moving, and where stones had fallen. Three weeks later, Biot sent a report to Chaptal and then, on July 17, he read his account to the Institute, where it was taken as the definitive proof that stones do fall from the sky. The National Institute printed his 45-page text (Biot 1803b) the following month (but did not issue it as a mémoire until 1806). Meanwhile, on July 21 Biot sent Pictet a copy of his letter to Chaptal saying (Biot 1803c:394):

> It is to you that we owe our knowledge of the works of Chladni and the English chemists on meteoritic masses. It is you who were the first, at the National Institute, to raise this great question, and you never have ceased to report facts and conjectures that will serve to decide it . . .You have earned a certain right to receive any new observations. . .

Biot described the following findings:

> The meteor did not burst at L’Aigle but at the distance of half a league from it . . . I traversed all the places where it had been heard; I collected and compared the accounts of the inhabitants; at last I found some of the stones themselves on the spot, and they exhibited to me physical characters which admit no doubt of the reality of their fall . . . No meteoric stones had been found in the hands of the inhabitants before the explosion . . .The founderies, iron works, and mines in the neighborhood . . . exhibited nothing . . . which had the least affinity to these substances. No traces of a volcano are found in the country.

Biot’s discovery of stones *in situ* indicates that Lambotin’s meteorite hunters had not cleared out the district after all. Biot constructed a map (Fig. 16) showing the meteorite strewn field as an ellipse measuring 10 × 4 km, with its long axis trending SE to NW, the direction of the fireball and also that of the Earth’s magnetic axis at that site—a point he emphasized in his account. The map was published with his report to the institute (Biot 1803b) and so, although Biot’s map was drawn later, it takes priority as having been published earlier than Marais’ map. Biot’s map is the more elegant of the two, and it gives a more accurate representation of the elliptical strewn field—as would be expected of a rising young physicist and mathematician. Biot called the stones “Laiglites,” and noted that the largest specimens, which were reported as the first to fall, were found near the southeastern end of the ellipse. This observation is not in question, although it contradicts our current expectation that the larger fragments will travel farthest. Biot concluded (1803c:405):

> I leave to the sagacity of the philosophers the numerous consequences that may be deduced from [these facts]; and I shall consider myself happy if they find that I have succeeded in placing beyond a doubt the most astonishing phenomenon ever observed by man.

Thus ended—very nearly—the controversy about falling stones. Matthieu Gounelle (2006) has argued persuasively that the scholarly community of France finally accepted the actuality of meteorites because of Biot’s finely written account of his field investigations at L’Aigle.

The Swan-Song of Guillaume DeLuc

On May 10, 1803, DeLuc wrote one more letter to *Bibliothèque Britannique*: “New Considerations on the Mass of Iron in Siberia and on Stones supposedly fallen from the Sky to the Earth.” In it, he made no mention of the fall at L’Aigle, presumably because the news had not reached him in Geneva. Protesting that his previous objections to fallen stones had not been answered, DeLuc scorned Howard’s remark that it is useless to argue against those who do not wish to believe in them. In closing, he declared that if the universe owes its existence to blind nature rather than to a powerful, wise, and intelligent Being who maintains order according to the laws He establishes, we are left in deep sadness, without consolation or hope. DeLuc (1803:112) added a postscript saying that he had just learned of the alleged fall of a stone at Salles. He critically analyzed the fireball reports in an effort to discredit the verity of the fall. Finally, DeLuc remarked on a recent report of a rain of limon (mud) at Friouli, Italy. Anyone who can believe that, he said, can easily believe in rains of stones, metals, and minerals. This letter generally is taken as the swan-song of Guillaume-Antoine DeLuc (e.g., Carozzi 1990:188) and, indeed, it was the last of his journal articles on this subject. However, Westrum (1978:484) refers to a review of Izarn’s book written by DeLuc in 1803 in which he very reluctantly accepted the reality of the fall at L’Aigle.[9]

An Analysis by Martin Klaproth

In 1803, the chemist, Martin Heinrich Klaproth in Berlin, published an analysis of a stone from Siena. He said (1803: 338) that after the fall at Siena in 1794, he had obtained stones and analyzed them, but he had not published his results then because the idea of fallen stones was so controversial. Klaproth did not say how soon he received the stones from Siena, but inasmuch as he wrote nothing at the time, we still may accept Chladni’s report that the first account of the Siena fall to be published in Germany appeared in 1796. After his initial publication in 1803, Klaproth continued to publish papers reporting his analyses of meteorites for the next nine years.

Joséf Izarn: *Lithologie Atmosphèrique*, 1803

In the spring of 1803, shortly after the fall at L'Aigle, a 422-page book by Joséf Izarn (1766–1834), a medical doctor and physicist, came off the press in Paris. Its long subtitle declared its contents: *Stones fallen from the Sky, or Atmospheric Lithology; presenting the Advance of Science on the Phenomena of Lightning Stones, Showers of stones, Stones Fallen from the Sky, etc.; with Many Unedited Observations Communicated by MM. Pictet, Sage, Darcet, and Vauquelin; with an Essay on the Theory of the Formation of These Stones*.

In part I, Izarn compiled reports and opinions on falling bodies that had been published in France between 1700 and 1803, including extracts of articles from foreign journals. This brought the whole story together concerning the beginnings of meteoritics. Part II was a critical examination of current opinions on the reality of the fall of stones from the atmosphere. Izarn compiled a table listing all of the falls of matter for which he could find references, from Moses' account of Sodom and Gomorrah to 1798. There were 34 of them. The majority of the falls were stones; two were irons, and a few were falls of mercury, sulfur, or viscous matter. His table also listed the four main hypotheses of the origin of falling stones—volcanoes or hurricanes, lightning striking terrestrial rock, concretions in the atmosphere, and masses foreign to our planet—along with the names of scientists who, in the past or present, advocated each one. Guillaume DeLuc appeared among those opining that the solid substances were ejected by terrestrial volcanoes or dropped by hurricanes.

Izarn began part III, with a quote from Vauquelin, who had said that the wisest course would be to avow freely that we are entirely ignorant of the origin of the stones and the causes that produced them. However, Izarn (1803:253) did not follow this excellent advice. As implied by his title, Izarn believed strongly in an origin by consolidation within the atmosphere and he devoted part III, by far the longest section of his book, to this theory, claiming that it was founded on the best established principles of physics and included no hypotheses. Izarn discussed Howard's results in detail and found no problem with the presence of nickel in atmospheric products.

Responses to Izarn

The following month, de Drée (1803c:77) published a short review of Izarn's book in *Bibliothèque Britannique* along with an updated version of Izarn's table (Fig. 16). Inasmuch as Izarn had written his book before the event, de Drée added the fall at L'Aigle and also the one at Sales (Salles), and the names of Delalande to those favoring an origin by volcanoes or hurricanes and Soldani to those favoring concretions in the atmosphere.

Lamétherie (1803a:441) published a 17-page extract of Izarn's book in the widely read *Journal de Physique, de Chemie, et d'Histoire Naturelle*. He said Izarn had rendered a true service in part I to savants who wished to study this extraordinary phenomenon, and that in part II he had assembled a wide spectrum of opinions on the matter and concluded that the fall of stones on the Earth is a genuine natural phenomenon. Lamétherie devoted his remaining 15 pages to outlining Izarn's theory of origin with virtually no commentary of his own.

In Germany, Izarn's book received a scathing review in *Annalen der Physik* by the editor, Ludwig Gilbert (1803:437), who wrote that Izarn seemed to be a stranger to most principles of physics, that many of his ideas were illogical, and that he clearly did not understand Dalton's theory of atmospheric gases or the teachings of his compatriots, Fourcroy and Berthollet, about chemical combinations and affinities.

With some exceptions, Izarn received mostly friendly reviews in England. In all these countries, a sizeable number of publications favoring an atmospheric origin followed that of Izarn.

A Meteorite Fall in America and the Thomas Jefferson Fable

On September 29, 1803, one J. Wheatcroft, an Englishman who had become an Associate of the Academy of Sciences, Arts and Belles Letters of Caen, in Normandy, wrote a letter to President Thomas Jefferson whom he addressed as an excellent naturalist and a friend to the Sciences. Wheatcroft included an eleven-page summary of Biot's observations of the fall of stones at L'Aigle the previous April. He then discussed the two leading theories of origin of such stones—volcanic eruptions on the Moon and formation within Earth's atmosphere—and listed his objections to both. Wheatcroft argued that fallen stones are derived from small comets, which he said, are innumerable in the solar system. Jefferson logged his receipt of this letter, which is archived in the Thomas Jefferson Papers in the Library of Congress, on February 25, 1804, but he made no record of his reply, if he wrote one (Robson 2006, personal communication). We cannot know whether Jefferson read either Wheatcroft's letter or Biot's original report.

On September 30, 1803, Robert Livingston (1746–1813), the U.S. Minister to France, wrote to Andrew Ellicott that philosophers in France had put almost beyond a doubt the fact of the fall of stones from the sky. Now they were disputing whether the stones are generated in the atmosphere or sent to us by eruptions on the Moon. He added that so much remains to be said on both sides that prudent men had not yet thought it proper to pronounce judgment. Ellicott (1754–1820) was an American astronomer, mathematician, and surveyor who was much in demand by federal, state, and city governments for accurate surveys of their properties. (In 1791, Thomas Jefferson, acting on President Washington's suggestion, had

Bibl. Brit. Sc. et Arts, Vol. XXIII, pag. 77.

OBSERVATIONS

ANCIENNES ET MODERNES

DE LA CHUTE DE DIVERSES SUBSTANCES SOLIDES SUR LA SURFACE DE LA TERRE.

SUBSTANCES QU'ON A DIT ÊTRE TOMBÉES.	LIEUX OU L'ON DIT LES AVOIR VU TOMBER.	ÉPOQUES DE LEUR CHUTE.	TÉMOINS OU NARRATEURS DU PHÉNOMÈNE.	PAGES et PARAGRAPHES où il en est fait mention. *Pages*	*Paragr.*
Pluie de pierres	à Rome	sous le règne de Tullius Hostilius	Tite-Live	14	14
Pluie de pierres	à Rome	consulat de C. Martius et Manlius Torq.	Julius Obsequens	17	16
Pluie de fer	dans la Lucanie	l'année avant la défaite de Crassus	Pline	19	19
Pluie de mercure	en Italie		Dion	20	22
Une pierre très-grande	près du fleuve Négos, dans la Thrace.	2e. année de la 78e. olympiade	Pline	21	23
Trois grandes pierres	dans la Thrace	l'an de J. C. 452	Chronique du Comte Marcellin	23	24
Pluie de feu	au Quesnoy	4 janvier 1717	M. Geoffroy le cadet	8	9
Une pierre de 72 livres	près de Larisse, en Macédoine	en janvier 1706	Paul Lucas	23	25
Env. 1200 pierres, une de 120 liv. Une autre de 60 livres	en Italie, près d'Abdua	en 1510	Cardan, Liv. 14, Ch. 72. (*Variét.*)	24	26
Une pierre de 59 livres	sur le mont Vaiser, en Provence	le 27 novembre 1627	Gassendi	24	27
Pluie de sable pendant 15 heures	dans la mer Atlantique	le 6 avril 1719	Le père La Feuillée	33	34
Pluie de soufre	Sodome et Gomorre		Moïse	51	63
Pluie sulphureuse	dans le duché de Mansfeld	en 1658	Spangenberg	51	63
Idem	à Copenhague	en 1646	Olaus Wormius	51	63
Pluie de soufre	à Brunswick	en octobre 1721	Siegesber	51	63
Pluie visqueuse (*Matière inconnue.*)	en Irlande	en 1695	Muschembroek	53	66
Deux grosses pierres pesant 20 liv.	à Liponas, en Bresse	en septembre 1753	M. Delalande	56	67
Une masse pierreuse	à Niort, en Normandie	en 1750	M. Delalande	59	75
Une pierre de 7 liv. et demie	à Lucé, dans le Maine	13 septembre 1768	M. Bachelay	62	83
Une pierre	à Aire, en Artois	en 1768	M. Gurson de Boyaval	60	78
Une pierre	dans le Cotentin	en 1768	M. Morand	60	78
Pluie de pierres très-étendue	aux environs d'Agen	le 24 juillet 1790.	MM. St.-Amans, Baudin, etc.	80	108 à 123
Environ 12 pierres	à Sienne (Toscanne)	juillet 1794.	Le Comte de Bristol	94	124
Une grosse pierre de 56 livres	à Wold-Cottage (comté d'Yorck)	13 décembre 1795	Le Capitaine Topham	101	131
Une pierre d'environ 20 livres	à Salé, département du Rhône	17 mars 1798.	MM. Celievre et de Drée	109	145
Une pierre de 10 livres	en Portugal	19 février 1796	M. Southey	174	269
Pluie de pierres	à Bénarès (Indes Orientales)	19 décembre 1798	John Loyd Williams, esq.	176	272
Pluie de pierres	à Plann, près Tabor, en Bohême	3 juillet 1753	De Born	182	281
Masse de feu de 70 pieds cubes	en Amérique	5 avril 1800.	Philosophical Magasine	216	338
Masse de fer de 14 quintaux	à Abakank, en Sibérie	très-ancienne	Pallas, Chladni, etc.	111 et 159	148 et 242
Pluie de pierres	à Barboutan, près Roquefort	en juillet 1789	Darcet fils, Lomet, etc.	255	386
Une grosse pierre de 260 livres	à Ensishem (Haut-Rhin)	7 novembre 1492	Butenchoën	328	74
Deux pierres de 200 liv. et 300 liv.	près Vérone	en 1672	Académie de Bourdelot	329	76
Une pierre de 20 livres	Sales près Ville-Franche Dép. du Rhône	le 22 vent. an VI (12 mars 1798).	De Drée.		
Plusieurs pierres de 10 à 17 livres	Près l'Aigle, (ci-dev. Normandie.)	le 6 flor. an XI (26 avril 1803)	Fourcroy.		

TABLEAU

DES

PRINCIPALES OPINIONS

Emises jusqu'à ce jour, sur les SUBSTANCES SOLIDES tombées sur notre Globe.

NOMS DES PHYSICIENS QUI LES ONT REGARDÉES COMME

DES PRODUITS LANCÉS DE LA TERRE PAR LES VOLCANS OU LES OURAGANS.	*Pages*	DES SUBSTANCES MINÉRALES FONDUES PAR LA FOUDRE, à l'endroit même où on les a trouvées.	*Pages*	DES CONCRÉTIONS FORMÉES DANS L'ATMOSPHÈRE.	*Pages*	DES MASSES ÉTRANGÈRES A NOTRE PLANÈTE.	*Pages*
Fréret.	15 et 16	Lemery	7	Descartes	72	Chladni	113
Gassendi	24	Les Académiciens	61	Lesser	73	Biot	234
Muschembroek	54 et 292	Agricola	73	Goyons-d'Arzas	92	Poisson	238
Barthold	72	Sthal	77	Sir Williams Hamilton	97	*Bibliothèque Britannique*,	n°. 174
G. A. Deluc	145	Gronberg	79	Edward King Soldani	100		
Delalande	59	Patrin	165	Eusebe Salverte	408		

Fig. 16. “Observations, ancient and modern of the fall of diverse solid substances on the surface of the Earth.” This is de Dree’s updated version of Izarn’s table in *Lithologie Atmosphèrique*. The two versions are identical except that de Drée added the falls at Sales (Salles) and L’Aigle, the name of Delalande to those favoring an origin from volcanoes or hurricanes, and of Soldani to those favoring consolidation in the atmosphere. The fall at Sales actually appears twice (second and eleventh from the end). Izarn dated it as occurring on March 17, 1798, giving de Drée as his source. To that entry, de Drée added the fall of March 12 without deleting Izarn’s entry. Note that although Enlightenment scholars had abolished falls of milk, blood, and flesh, which were reported in ancient and Medieval times, they retained substances such as mercury, sulfur, and viscous matter. (From de Drée 1803c.)

asked Ellicott to survey the site of the ten-mile-square tract on the Potomac River that was to become the permanent site of the nation's capitol.)

When Ellicott received Livingston's report from France, he passed this information along to Thomas Jefferson (1743–1826) who was then serving his first term as president of the United States. On 1803 December 23, Jefferson responded to Ellicott that he found nothing surprising in the raining of stones in France, nor yet had they been mill-stones. He observed that there were in France more real philosophers than in any country on Earth; but also a greater proportion of pseudo-philosophers (Burke 1986:56).

Ellicott remained skeptical of falls until October 1805 when he received additional publications from France that convinced him that stones, differing from ordinary stones, actually do fall from the sky, and they are formed within the atmosphere. When he informed the president of his new belief, Jefferson replied on October 25, 1805, that he had not read all the papers to which Ellicott referred, but he had read Izarn's *Lithologie Atmosphèrique*. He could not say that he disbelieved nor yet that he believed it—chemistry was too much in its infancy to satisfy us that lapidific elements exist in the atmosphere and can be formed into stones there. Burke (1986:57) pointed out that in this passage, Jefferson appeared to be more doubtful about their formation in the atmosphere than about the fall of stones.

The Fall at Weston, Connecticut

Two years later, at 6:30 in the morning of December 14, 1807, a brilliant fireball, appearing to be half the diameter of the full Moon, was seen by early risers streaking southward over much of New England from Canada to the Delaware River (Hoffleit 1988:120). Over southeastern Connecticut, the fireball emitted three dazzling flashes and thirty to forty seconds later three tremendous explosions occurred followed by loud rumbling sounds. Stones fell over three areas within a space of ten miles within Fairfield County. The first and most northerly site of fall was in the township of Huntington where it bordered that of Weston, the next two were within Weston, which was a larger township at that time than it is now.

At that moment Mr. Isaac Bronson, a merchant, had just passed through Rye, New York, on a night stage-coach from New York City. The brilliant flashes illuminated his darkened coach although the curtains were drawn, and he heard the detonations at close range. On arriving home, he found that stones had fallen just over three miles from his house in the village of Greenfield. Despite his night spent sitting up in the cold stage, Bronson met with the Reverend Mr. Holly from his parish and they spent all day of December 14 visiting places where stones had fallen and interviewing witnesses, of which there were hundreds in the area. Bronson noted that the stones were magnetic, heavier than granite, and covered by a smooth black glazed crust except on broken surfaces which were the color of bluish lead. He observed that one of the largest stones, which must have weighed more than 100 pounds, had struck a rock and shattered into many pieces. Bronson purchased a 12-pound fragment of it to present to some public institution. On Saturday, December 19, Bronson described his observations in a letter to *The New York Spectator*, which printed it on page 1 of its edition on Saturday, January 2, 1808.

Dr. Benjamin Silliman (1779–1864), the newly appointed professor of chemistry at Yale College in New Haven, Connecticut, quickly learned of the fall of stones, and on December 18 he wrote to his mother that he was off to Weston to investigate the circumstances. Only six months earlier, in May 1806, Silliman had returned home from England and Scotland where he had spent twelve months purchasing books and equipment for his chemistry laboratory and learning about the latest analytical techniques. He had become familiar with the meteorite analyses published by Howard, Fourcroy, Vauquelin, and Klaproth and understood that stones should be separated into their main constituents and the metal grains analyzed for nickel.

Silliman and his colleague, James L. Kingsley (1778–1852), the Yale professor of classical languages, arrived in Weston on Monday, December 21 and spent the next two days visiting each of the three sites of fall and interviewing witnesses. Along with much valuable information, they found alarming instances of people hacking the stones to pieces, dissolving them in crucibles, heating them on forges, and pounding them on anvils in hopes of finding gold and silver (Narendra 1978). With considerable difficulty, Silliman and Kingsley obtained fragments of each stone that had fallen. They spent their final hours in the field on a fruitless search of Tashowa (or Taskaway) Hill in Weston where one stone had been recovered and another had been heard to strike the ground. They returned to New Haven on Thursday, December 24, the day before Christmas.

On that same day, Mrs. S. L. Mitchill, in New York City, wrote a detailed description of the fall at Weston in a letter to her husband in Washington. The Honorable Samuel Latham Mitchill (1764–1831), was a medical doctor and professor of chemistry and natural history at Columbia College with wide-ranging interests. He published papers on geology, mineralogy, mines, and topographic effects of earthquakes. Mitchill also was well read in classical and modern history and literature, and he corresponded with many of the scientific and literary men of his day. Meanwhile, he pursued a distinguished career in the political life of the young republic. Beginning in 1790, Mitchill served three non-consecutive terms in the New York State Legislature, four in the U.S. House of Representatives, and one term in the Senate. Given the breadth of his knowledge, his opinions were eagerly sought after with respect to the merits of useful inventions, new discoveries, public works, and political and social developments at home and abroad. President Jefferson referred to him as the "Congressional Dictionary" (*Harper's New Monthly Magazine* 1879:740).

In his later years, Mitchill turned over his lifetime accumulation of manuscripts and correspondence to his brother-in-law, Dr. Samuel Akerly, who began writing his biography. Unfortunately, this invaluable archive was lost in a fire that destroyed the house in which it was stored. Happily for historians, however, Mrs. Mitchill had saved out his letters to her and in 1879 these were published in *Harper's New Monthly Magazine*. Among them is a letter Mitchill, then serving in the Senate, wrote to his wife on December 30, praising the excellence of her writing about the recent fall of meteoric stones in Connecticut. Mitchill (1807:752) wrote:

> [Your letter] preceded all the letters to the Connecticut delegation, and even outran the newspapers. It was, therefore, the great authority on which the news was told, and has been quoted to Senators, Representatives, and other great and curious personages . . . Two days after the town had been agitated by your letter, a full and circumstantial account of the occurrences reached me from Fairfield. Two gentlemen, Messers. Holley (sic) and Bronson, spent a day investigating the facts. Their narrative was accompanied with a specimen of the stone, and the whole story was such a verification of yours . . . that you have found great credit for your intelligence.

He added that the stone was exceedingly like the one Mr. Cabell had given her from France (so Mrs. Mitchill already possessed a meteorite, perhaps a piece of Ensisheim or L'Aigle, which, like Weston, were ordinary chondrites).

The timing of Mitchill's letter presents a conundrum. As noted above, Mrs. Mitchill wrote to him on December 24, ten days after the fall, and he answered her six days later on the 30th. Other sources have indicated that it could take a week for mail to travel between New York and Washington, but Mitchill must have received her letter within three, or four days, at most, if he had time to publicize the news for two days before he received the letter and stone from Bronson and Holly. We can only wonder how her letter reached Mitchill so quickly. Did Mrs. Mitchill send it to Washington by courier? We also may wonder from whom Mrs. Mitchill obtained her detailed information about the fall. Perhaps it was described to her by one of her evening callers, who often stopped by to hear the latest news in Mitchill's letters from Washington.

Mitchill claimed the pleasure of being the first person in Washington to receive news of the fall and to tell it around the city. Meanwhile, in an effort to issue the first published report of it, Silliman and Kingsley sent a preliminary description of the fall phenomena and the stones to *The Connecticut Herald*, in New Haven, which published it on December 29, 1807. Four days later, Bronson's letter appeared in *The New York Spectator*. Immediately following Bronson's letter, the editor of the paper inserted two short notices taken from local newspapers. The first, from Bridgeport, Connecticut, dated December 24, was titled: "Terrestrial Comet." It stated that on the morning of the 14th a "Terrestrial Comet" exploded nearly over the town of Weston, about nine miles from Bridgeport. It described the comet's size, brilliance, course, and explosion, and said the stone appeared to have been dissolved and concreted again, and strongly impregnated with iron. The notice continued:

> We understand that the intention of the learned faculty of Yale College is extended to this remarkable phenomenon, and it will yield something new and interesting if pursued intensively, which we presume it will be. Mr. Edward King, of London, has published remarks on the falling of stones from our atmosphere both in antient and modern times. Mr. King's enquiry was excited by the remarkable explosions which took place in Tuscany [Siena], on the 16th of June, 1794.

The second, much shorter, notice came from a paper in Wardsbridge, Connecticut. Dated December 25, it described the fireball as an uncommonly large meteor resembling a fiery-tailed comet. The first of these notices indicates that at least one local newspaper editor was familiar with Edward King's book that had been published eleven years earlier in England.

Some days after Silliman and Kingsley left Weston, the stone they had been searching for on Tashowa Hill was found by a little boy of the Jennings family. It was a fine specimen weighing thirty six and one-half pounds, the largest one of the shower to be collected intact. Although some of his neighbors who had met Silliman and Kingsley urged Mr. Jennings to give it to Yale, and Bronson offered to buy it for five dollars, Jennings put the stone up for sale in New York City.

On February 8, 1808, a Mr. Daniel Salmon, who gave his return address as New York, No. 98 Maiden Lane, wrote as follows to President Jefferson (spelling as in the original):

> Sir, Being Solissited by a Number of Gentlemen in Fairfield County, State of Connecticut, and in particular by many in the town of Trumbull in said County in which town is the place of my Residence also by many in this City [New York] to communicate to your Excellency the Intelligence of a large mass of the late Meteor Stone which fell Near my house on the morning of the 14th Day of December last . . . I take the liberty then to address you and hereby to inform your Excellency that I Now hold and am possess'd of the largest fragment of the meteor Stone which has yet or proverbelly ever will be found weighing 37 pounds . . . I was an Eye and Ear witness with many of my Neighbours that a Stone fell in the same field where this fragment was found to wit on a field sewed with Rye after a Crop of Oats this piece was found 3 feet below the surface and many Spires of green Rye and Oat Stubbel at the bottom of the Cavity and on said fragment . . . this must be an Evidence that it fell from the atmosphere it has also ben Carfully Examined by the professional Gentelmen in Connecticut and at this place and they all without hesitation, Declare this piece to be of a Meteoric production . . .
>
> I have been Solicited to present this fragment at the Seat of Government and in particular to your Excellency and the present executive together with the National legislator that they might have the pleasure of viewing it . . . I should take Great pleasure in being the bearer of this New Visitor in the united States and to give the Curious an opportunity of Seing this Mass was not the Distance so great and my Resours small . . . may your Excellency be under the protection of him by whom kings Reign and
>
> I am Respectfully your Obedient and Very Hum'le Servt. Daniel Salmon.
>
> N.B. Dr Archibald Brace in this City having attentively

> Escmined this Meteor stone has addressed to me a note in the following words (viz) the Stone in your possession from its similarity with those in the Cabinet of mr. Greville in London and mr. de Drie in France (who possess the largest Collection of these meteor Stones) and likewise from its agreeing in all its Externall Characters with a fragment in my possession of the one that fell at Ensisheim in upper Alsace in 1492 . . . I have no Doubt that this mass weighing 37 pounds is of Meteoric production we have also the Opinion of mr. B. Sileman professor of chimestry at yale College, and of Doctr. John Kemp and Doctr. James S. Stringham of this City all agreeing with Dr. Brace. Yours as before D:S.

This letter tells us, among other things, that a piece of the great stone of Ensisheim was in the collection of Dr. Archibald Bruce (1777–1818) of New York City, where it helped to identify a stone from Weston as a meteorite. It does not tell us who Daniel Salmon was or by what right he could claim to be in possession of the intact meteorite. He said he lived in Trumbull, Connecticut, close to a site of the fall, but he headed his letter with an address at 98 Maiden Lane in New York City. Maiden Lane was a neighborhood where lotteries and auctions were conducted. Notices of such activities appear on the same page of *The New York Spectator* with Bronson's letter. We only can speculate on what role Salmon played there. Was he serving as an agent for Jenning's? Did he describe the stone to the President in hopes of enhancing its value? Was Jennings aware of Salmon's letter to Jefferson?

Jefferson received Salmon's letter on February 14 and replied on the following day, February 15, 1808. He wrote that a more effectual examination might be made by a scientific society, such as the Philosophical Society of Philadelphia, than by members the national legislature, among whom some fragments of these stones already had been circulated. He added (in Bergh 1907:440):

> We certainly are not to deny what we cannot account for . . . It may be very difficult to explain how the stone you possess came into the position in which it was found. But is it easier to explain how it got into the clouds from whence it is supposed to have fallen? The actual fact, however, is the thing to be established.

This measured response in which he reserves judgment pending further study, was Jefferson's only written commentary about the fall of meteorites at Weston or elsewhere. Whoever Mr. Salmon was, and whether or not his claims were genuine, we are indebted to him for having elicited a letter about the Weston meteorite from President Jefferson.

Much as he wished to possess that stone, Professor Silliman could not offer a high enough bid, so he had to await further developments. He did not await them long. In 1808, the same year that Mr. Salmon wrote to the president, the stone was purchased by Colonel George Gibbs (1776–1833), of Newport Rhode Island, the owner of a famous collection consisting of some 10,000 specimens of rocks and minerals. In 1810 Gibbs loaned half of his collection to Yale, to be used for study and research, and in 1812 he loaned the other half to Yale. Finally, in 1824, the trustees of Yale College and the citizens of New Haven purchased Gibbs's entire collection for $20,000. At last, Yale possessed the intact Weston stone, weighing about 36.5 pounds (149 kg), which, at that time, was the largest known intact piece of any stony meteorite. It formed the basis of the Yale meteorite collection, and today it is the only remaining specimen of the Weston fall in that collection (Hoffleit 1988).

In 1808, Silliman and Kingsley revised and enlarged the article they had published in the Connecticut Herald and submitted it as a memoir to the American Philosophical Society. In it, Kingsley described the fireball, the fall, and the character and distribution of the stones, and Silliman published his chemical analyses of the bulk stone and five of its constituents: the pyrites, the malleable iron, the black irregular masses, the crust, and the globular bodies. He described the physical character of each concentrate and the chemical technique he applied to it. His was the first chemical analysis of a meteorite in America and it was equal in quality to any done in Europe.

For the origin of the stones, Silliman and Kingsley favored the hypothesis that had been proposed by President Thomas Clap of Yale (1703–1767), and published posthumously in 1781, that fireballs are terrestrial comets, circling the Earth in long elliptical orbits with a perigee of 25 miles and apogee of about 4,000 miles. They concluded that, on closest approach, such a comet had shed some stones at Weston and continued on its rounds.

On 1808 March 4, the memoir by Silliman and Kingsley was read to the American Philosophical Society and assigned to referees Woodhouse, Hare, and Cloud, who were so favorably impressed that they recommended publication in the forthcoming volume of the society's *Transactions* (Marvin 1979), which, however, would not appear until the following year. Meanwhile, their work became widely known in Europe when Silliman submitted their paper to various European editors with high hopes of reaching a readership knowledgeable about meteorites and their chemistry. His hopes were quickly fulfilled. During 1808, excerpts or abstracts appeared in several well-known European journals, including the *Philosophical Magazine*, *Bibliothèque Britannique*, *Annalen der Physik*, *Journal de Physique, de Chemie, et d'Histoire Naturelle*, and *Journal des Mines*. A copy was read to the Royal Society in London, and a newspaper article on it had been translated into French and read to the National Institute in Paris before a rapt audience including Fourcroy, Vauquelin, Berthollet, Laplace, Lagrange, and Biot (Brown 1989:236). All of this attention served not only to raise Silliman, who was at the very beginning of his career, into the ranks of internationally known scientists, but also to elevate the status of Yale University and, indeed, of American science, itself—even before the publication of the memoir in the *Transactions of the American Philosophical Society* in 1809.

Chladni (1819:148–149, 282–284) discussed the Weston fireball and the composition of the stones in his book *Feuer-Meteore*. In later years when Silliman was working on his memoirs, he wrote (Narendra 1978:11): "In Europe I had become acquainted with meteorites and the phenomena that usually attend their fall . . . I did not dream of being favored by an event of this kind in my own vicinity and occurring on a scale truly magnificent."

Thomas Jefferson died in 1826 on the 4th of July. Three months later, on October 11, a commemorative meeting was held at the Lyceum of Natural History in New York. The invited eulogist was Samuel Latham Mitchill. In his talk, Mitchill recalled Jefferson's many intellectual and political accomplishments, and then, as he was drawing to a close, Mitchill (1826:35–36) said it might be proper for him to mention an anecdote that showed the wariness with which Jefferson sometimes credited intelligence. Mitchill recalled that in 1807 he was the first person in Washington to receive the news and a specimen from the fall of stones at Weston—even before the representatives from Connecticut heard of it. He said his news excited a great sensation, particularly as the whim was then prevalent that these productions were ejected from the Moon by volcanic fire. A senator living in his boarding house was to dine with Jefferson that very day, so he prevailed upon Mitchill to loan him the letter and the stone so he could show them to the "philosopher of Monticello." The senator returned crestfallen at Jefferson's response: "J. said he could answer it in five words: 'It is all a lie.'" Mitchill hastened to explain Jefferson's attitude by citing a rather weak non sequitur. He said Jefferson had been much imposed upon by reports of a mountain of salt in the Missouri territory that had proved to be false. Now, he was resolutely on his guard against a trick by a shower of stones.

To us, it may seem out of character for Jefferson, who kept in touch with the scientific literature of Europe, had received from Wheatcroft a portion of Biot's report of the fall at L'Aigle in 1803, and had read Izarn's book by 1805, to be so impulsively scornful of fallen stones in 1807. By that time, more than 150 articles on meteorites had been abstracted in the journals of England, France, Germany, and Italy (Brown 1953). We also may find it puzzling that Mitchill, who had not mentioned Jefferson among the "great and curious personages" to whom he had related the news in 1807, should suddenly tell this tale after eighteen years of silence. Perhaps we can understand why he would prefer not to tell it while Jefferson lived, but we cannot agree with him that it seems proper for a eulogy. Indeed, this long-delayed tale told by a person not present at the scene, might well have been dismissed as hearsay by a court of law, and that is approximately what happened to it in the court of public opinion. From the first, Mitchill's version, "It is all a lie," was rarely quoted and it never entered the popular literature. However, at some later time a peculiar variation of it entered into the mythos of meteoritics, to wit:

> Thomas Jefferson said it would be easier to believe that two Yankee professors would lie than that stones would fall from the sky.

To whom did he say that, and when? On the day in late December 1807, when Mitchill's stone was shown to him, neither Mitchill nor Jefferson could have known that Silliman and Kingsley had visited Weston. Jefferson expressed no annoyance toward Yankee professors on that occasion or in the letter he wrote to Mr. Salmon s few weeks later on February 8, 1808. In fact, while he lived, Jefferson never wrote, nor was he ever quoted as mentioning fallen stones again. Clearly, the Yankee professors were inserted into the story by some wag at a later date.

In 1990, the historian, Silvio Bedini (1990:388) wrote that the Yankee professors were a fabrication which first appeared in 1874 in a paper by Silliman's son, Benjamin, Jr. and T. S. Hunt. But the Silliman and Hunt paper appeared in 1847 (not 1874) and it is strictly about an iron meteorite with no mention of Yankee professors. On June 24, 1884, Charles Upham Shepard (1804–1886), the curator of meteorites at Amherst College in Massachusetts, unveiled a bronze statue of Benjamin Silliman at a memorial service for him at Yale. Shepard (1884) remarked that the fall of the Weston meteorite enabled Professor Silliman, along with Professor Kingsley, to describe a phenomenon whose reality was until then universally doubted. He added: "the great Jefferson even having said of the reported fall that it is more natural for men to lie than for stones to fall from the sky." Shepard did not identify Silliman and Kingsley as Yankees; perhaps because he felt it would be tactless to do so on that occasion. Or maybe they were not yet part of the story as he had heard it (Marvin 1986:146; 2006:52).

Another view of Jefferson's response, "It is all a lie," was discussed in 1943 by Harlow Shapley (1885–1972) director of the Harvard College Observatory. Shapley (1943:234) wrote: "He did not like this Connecticut story. And he did not like the way the Connecticut Yankees pronounced their Latin, either. And for their part, it was notorious how vigorously much of Connecticut disliked this Virginia advocate of religious tolerance." Without referring to Yankee professors, Shapley suggests that political resentments momentarily overrode Jefferson's sober scientific judgment.

Indeed, Jefferson had much to worry about at that moment. His Embargo Act, designed to stop trade with Great Britain in order to pressure that country into recognizing American neutrality on the seas, had gone into effect a few days earlier, on December 22, 1807. He knew that closing American ports would bring great hardship to all the coastal cities, and that New Englanders, in particular, would attempt to run the blockades and to smuggle goods overland into Canada. (They did both, with some success but to no lasting effect.) Jefferson had hoped to prevail by means short of war, but he succeeded mainly in postponing war until 1812, when it took place in the administration of his successor, James Madison.

In all likelihood, we never shall know when or where the "Yankee professors" made their first appearance in the literature. In 1929, George P. Merrill (1854–1929) head curator of geology at the Smithsonian Institution, remarked that the quotation had been long since and repeatedly denied. Nevertheless, today, after nearly one more century of denials, it is almost impossible to read an account of the history of meteoritics without finding Jefferson's famous quote about Yankee professors. There are signs of progress, however. Richard Binzel of the Massachusetts Institute of Technology opened his foreword to the magnificent new volume, *Meteorites and the Early Solar System II*, edited by D. S. Lauretta and H. Y. McSween, Jr. (2006), with what he calls "the apocryphal statement attributed to Thomas Jefferson." This is a clear, unambiguous declaration that Binzel does not believe Jefferson said it. On this encouraging note, perhaps we may hope that others will follow and we soon may be able to declare an end to the unfounded fable of Thomas Jefferson and the Yankee professors.

Metallography of Irons: Alois von Widmanstätten, 1808

In 1808, Alois Beck von Widmanstätten (1753–1849), director of the Imperial Industrial Products Cabinet in Vienna, cut, polished, and heated a small slab from the Hraschina iron meteorite over an open flame. As he watched, a pattern developed revealing the presence of at least two metals that oxidized at different rates. He then etched the slab with nitric acid which revealed a strong pattern of criss-crossing lamellae. To von Widmanstätten, who came from a family of printers, a slab of etched iron meteorite looked like a printer's plate (Clarke 1996). So he began polishing and etching iron meteorites, inking their surfaces, and printing the patterns on paper. Von Widmanstätten never published his "nature-prints," but he showed them to colleagues and friends who began calling them Widmanstätten figures in their publications (e.g., Neumann 1812; Schweigger 1813). In 1819, Chladni issued his book, *Über Feuer-Meteore, und über die mit denselben herabgefallenen Massen*, in which he reviewed what had been learned about meteorites and fireballs up until then. His title page indicates that the book is accompanied by a supplement including ten plates with explanations by Carl von Schreibers (1775–1852), director of the Imperial Natural History Cabinet at Vienna. Von Schreiber's supplement appeared a year later in 1820, under the title: *Beiträge zur Geschichte und Kenntniss meteorischer Stein und Metallmassen*. It consists of 97 large folio pages (8.5 × 14") making it a total mismatch with Chladni's quarto volume of 5 × 8-inch pages. Today the supplement is commonly cataloged under Chladni, but it functions as an independent work. Its main value is that it includes nine plates of meteorites, five of which illustrate Widmanstätten figures. Some of them were reproduced by a lithographic technique but at least one of them (Fig. 17) is a true "nature-print" of the Elbogen iron. It clearly depicts the intriguing patterns that the world has ever since called Widmanstätten figures (or patterns, or structures). Another plate (Fig. 18) consists of lithographs of stones from four historic falls.

Von Schreibers (1820) wrote that all iron meteorites have Widmanstätten figures and, despite rare instances of irons without them, these figures were taken as diagnostic of a meteoritic origin until 1847, when an iron without them fell at Braunau in Bohemia (Czech Republic). Later that year, Haidinger (1847) wrote that the Braunau iron was homogeneous with a cubic structure. It was the prototype of the class of irons we call "hexahedrites" which contain <6 wt% of Ni. It was later learned that irons containing >15% Ni also have a compact structure lacking Widmanstätten figures. In 1872, these Ni-rich irons were named "ataxites" by Gustav Tschermak (1836–1927), director of the Mineralogical-Petrological Institute in Vienna. Both hexahedrites and ataxites are rare in comparison with the abundant octahedrites with their intermediate nickel contents and Widmanstätten figures.

In the early 1800s, several investigators dissolved pieces of iron meteorites in acid and recovered metals of three different compositions. But not until 1861 did the German chemist and industrialist Karl Ludwig von Reichenbach (1788–1869) analyze and name the three metals in iron meteorites: kamacite (light gray lamellae with <6% Ni), taenite (thin, bright lamellae with 6–15% Ni), and plessite (dark gray, fine-grained metal filling interstices between lamellae). Depending on the crystallographic orientation at which a slice is taken, the lamellae will be seen to enclose triangular, square, or rhombic fields of plessite that looks like smooth metal but is, in fact, an intimate admixture of kamacite and taenite.

In the 1880s, structural studies by both Tschermak and Brezina proved that the kamacite and taenite lamellae lie parallel to the octahedral planes of a face-centered cube, thus forming the octahedral patterns for which these irons are named octahedrites.

For the next 130 years, from 1808 to 1939, von Widmanstätten was credited as the earliest discoverer of the metallurgical patterns that are named for him in iron meteorites. The first intimation of a possible rival arose indirectly in 1939 when Robert T. Gunther (1869–1940), the Oxford historian and antiquary with a special interest in the Naples area, examined a mineral collection that contained numerous fine specimens marked "Dr. T." Gunther (1939) had no clue to the identity of Dr. T. until he came upon a sample of Vesuvian lava that had been worked into a commemorative medal honoring the French geologist, Diodato Dolomieu (1750–1801). The back of the medal was impressed with the name and date: "G. Thomson Anglus 1805." Seeking further information, Gunther contacted Professor Alfred Lacroix (1863–1948), at the Muséum National d'Histoire Naturelle in Paris, who found a letter in

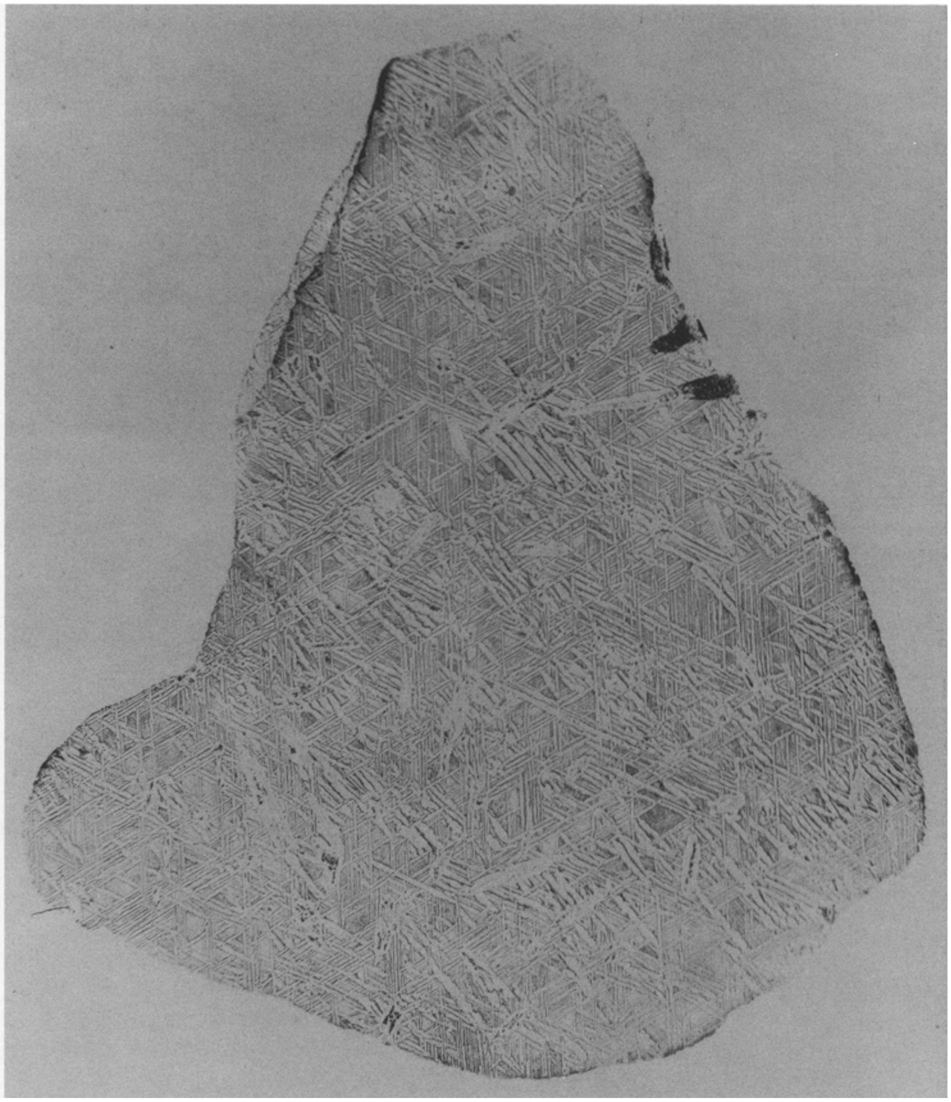


Fig. 17. "Nature-print" of the Elbogen iron by Alois von Widmanstätten who polished, etched, and inked the surface and printed it on paper. (Plate 9 from the supplement to Chladni's book of 1819 by von Schreibers [1820].)

the archives that had been sent in 1801 from Naples in to the paleontologist, Georges Cuvier (1769–1832), by "G. Thomson, già Professore di Anatomia à Oxford."

The rest was simple, wrote Gunther: G. Thomson was none other than William Thomson, the English medical doctor and mineralogist who, he said, unbeknown to most Englishmen, had led two lives that seemed never to have been correlated. Gunther published his discovery in a short article in the April 22, 1939, issue of *Nature* titled: "Dr. William Thomson, F.R.S., a Forgotten English Mineralogist, 1761–ca. 1806." Gunther briefly described Thomson's education in England and noted that he had been elected to the Royal Society on the recommendations of several of the most illustrious men of his time. Gunther mentioned Thomson's abrupt resignation in 1790 from all of his positions in England and his taking up of residence in Naples where he assumed the name, Guliermo.

Gunther devoted much of his short article to descriptions of Thomson's famous collection of natural and artificial materials formed or altered during eruptions of Mt. Vesuvius. Then, in two sentences, Gunther (1939:668) casually remarked on a subject of special interest to us:

> In Siena he made the acquaintance of Professor Soldani, who in after years doubtless secured the publication of his last paper, on the metallurgy of the Pallas meteorite, in the Atti of the Siena Academy. His engraving of its crystalline structure shows an anticipation of Widmanstätten figures of 1808.

Gunther searched the contemporary literature but found no references to Thomson's paper. He concluded that Thomson had published it in too obscure a journal for it to be noticed.

Gunther's offhand statement of Thomson's anticipation of the Widmanstätten figures elicited a letter to *Nature* from

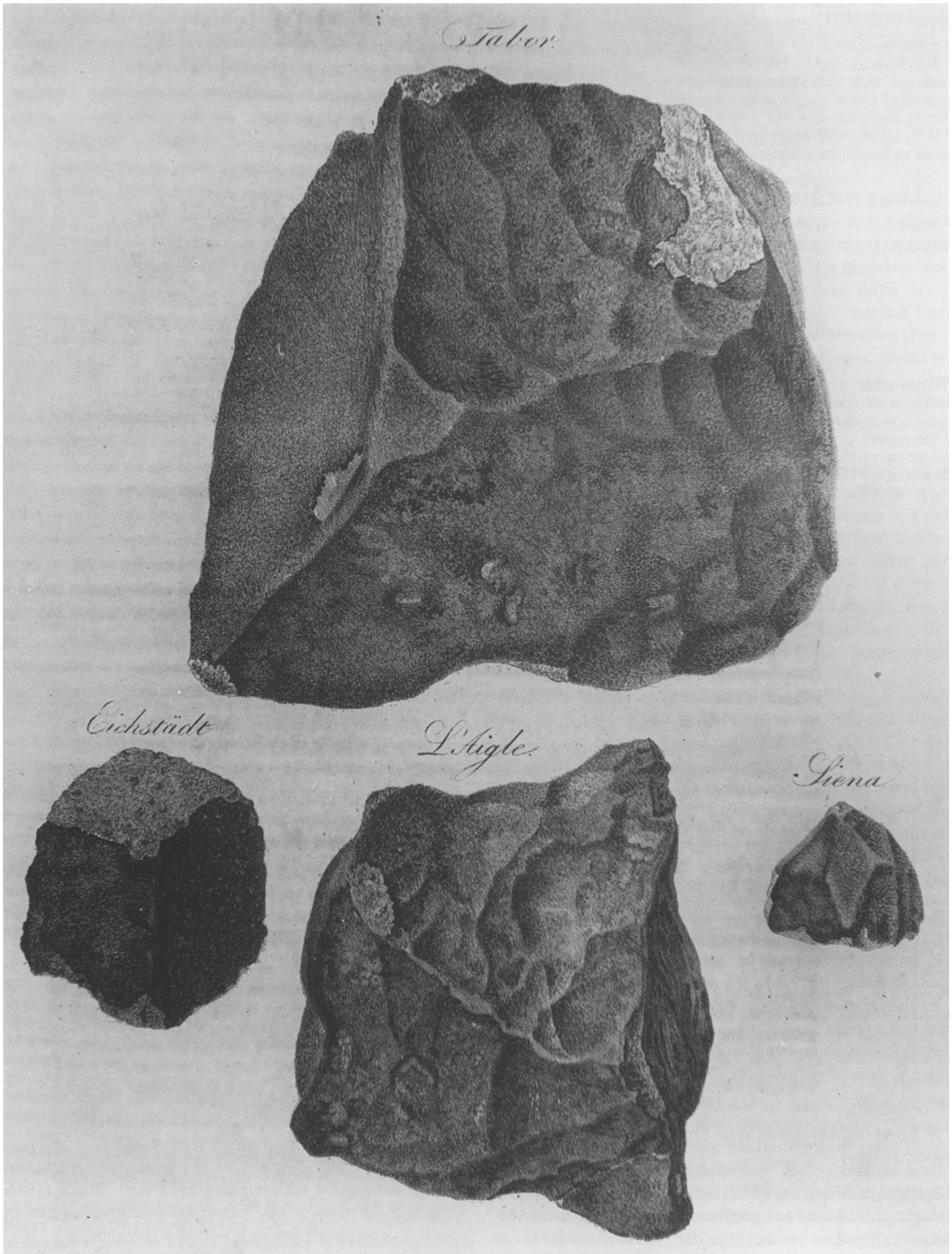


Fig. 18. Engravings of stones from four historic falls: Eichstädt, Tabor, Siena, and L'Aigle. (Plate II from the supplement to Chladni's book of 1819 by von Schreibers [1820].)

Max Hey (1905–1984) of the Department of Mineralogy of the British Museum (Natural History). Hey looked up the 1808 issue of the *Atti dell'Accademia delle Scienze di Siena* that contained Thomson's article on the Krasnojarsk meteorite, which, he noted, was dated "February 6, 1804." Hey remarked that the article is of particular interest to us because it shows that Thomson studied the action of dilute nitric acid on the nickel-iron and fully described and pictured the etch figures, thus anticipating the work of von Widmanstätten which, was carried out in 1808 and published first in 1812 (by K. A. Neumann). Although he documented Thomson's priority of publication, Hey made no suggestion that the etch figures should be renamed for him. Here the matter rested for two more decades.

In 1960, an article by Friedrich Adolf Paneth (1887–1958) titled, "The discovery and earliest reproductions of the Widmanstätten figures," was published posthumously in *Geochimica et Cosmochimica Acta*. Paneth, who had been Director of the Max Planck Institut für Chemie in Mainz, made no reference to R. T. Gunther's article or to Max Hey's letter in *Nature*, but he was aware that there were two claimants to the discovery of the remarkable etch figures of meteoritic nickel-iron. One, wrote Paneth (1960:176), was, of course, von Widmanstätten who discovered this phenomenon in 1808, displayed prints of it he had made to his colleagues, and devoted many years to its study, "so that its connexion with his name is fully justified." The other one was an Englishman living in Naples called G. Thomson, who discovered the etch figures at almost exactly the same time von Widmanstätten did and published his observations in 1808 in the *Atti dell'Accademia delle Scienze di Siena*. Paneth said that this clearly established Thomson's priority of publication, particularly for his illustration, which was the first visual reproduction of the Widmanstätten figures. Nevertheless, Paneth did not suggest that the figures should be renamed for Thomson. Paneth may not have known that Thomson died in 1806 and that his article of 1808 was published posthumously by Soldani. Actually, in 1808, Soldani published two of Thomson's papers posthumously; the other one was the Italian translation of Thomson's extract in French of Domenico Tata's treatise of 1794 on the Siena fall.

Paneth (1960:177) expressed a strong dislike of von Schreibers' supplement to Chladni's book: "In his own very bad style, characterized by sentences of monstrous length, Schreibers presents his personal views, which sometimes are opposed to those of Chladni's book." But Paneth found much of value in Schreibers's nine plates illustrating numerous meteorites, of which five are irons showing the Widmanstätten figures.

With his interest in Thomson aroused, Paneth searched for information on him but found none in the *Oxford Dictionary of National Biography*, nor did he find any mention of him in Chladni's book of 1819. This surprised him because Chladni was believed to have been extraordinarily well-read of books and papers on meteorites. Then Paneth noted that von Schreibers (1820:15) had said that the stone from Siena in the Vienna collections had passed through the hands of a Thomson in Naples to whom it had been sent by Father Soldani. Furthermore, von Schreibers (1820:15) remarked in a footnote that the meteorite shower of Siena was known abroad mainly because three learned Englishmen, Thomson, Hamilton, and Lord Bristol (Hervey) had taken an interest in it. Paneth noted that Hamilton returned to England in 1800, but Thomson must have stayed on in Naples because Soldani (1808) mentions receiving a scientific paper from him in 1803. It appears that neither Gunther nor Paneth understood the circumstances under which Thomson left England. These are stated by Torrens (2004) in his article on Thomson in the most recent edition of the *Oxford Dictionary of National Biography.* He tells us that Thomson was stripped of his studentship and his degrees and banished from Oxford in November 1790 under suspicion of sodomy and other detestable practices with a servant boy.

Paneth emphasized what a heroic job Thomson did by working on a pallasite, which is extremely unsuitable in comparison with an iron meteorite. One of Paneth's figures shows a few very narrow slivers of etched metal on the surface of the deeply pitted Pallas stony iron. It was from such minute surfaces that Thomson drew the first illustrations of the Widmanstätten pattern at the cost of severe eye strain. Paneth pointed out that the title page of Thomson's Italian text refers to it as a translation from an English manuscript. But, he added that we can scarcely hope to find the original today.

In 1962, Cyril Stanley Smith (1903–1992), professor of metallurgy and history of science at the Massachusetts Institute of Technology, responded to Paneth's paper with a note in *Geochimica et Cosmochimica Acta*. Smith had read the papers by Gunther and Hey and he pointed out, once again, that the letter of transmittal of Thomson's article in the Atti of 1808 bears the date: "6. Febbrajo 1804," clearly indicating an earlier date for the original manuscript. Smith (1962) who had written a book in 1960 on the history of metallography, was particularly interested in Thomson's clear statement that the popular superstition is false that a crystalline metal must be brittle. He added that this belief was so firmly entrenched that the converse observation that malleable metals could be crystalline was not generally accepted until many decades later. This shows us the difficulties Thomson faced in trying to explain the malleability of the iron with its strongly crystalline structure.

No English original of Thomson's 1808 article published in Italian has ever been found, but in the early 1960s a French version was discovered by Marjorie Hooker (1908–1976) of the U.S. Geological Survey when she was compiling a bibliography of Thomson's writings. The article had been in plain sight for more than 150 years; it was published in two parts in 1804, volume 27 of *Bibliothèque Britannique*! Its title began with four words in English and continued in French: "On the Malleable Iron, etc. Essai sur le fer malléable trouvé en Sibérie par le Prof. Pallas" (Traduction libre). The page of drawings (Fig. 19), was duplicated in the Italian version of 1808. The article in *Bibliothèque Britannique* clearly qualifies Thomson as the discoverer of the metallurgical patterns that are unique to the nickel-iron in meteorites. These figures could and, indeed, should have been named for Thomson in 1804, or in any later year up to 1812, when Neumann first published a paper in which he called them Widmanstätten figures. But Thomson's paper seems to have met with a resounding silence. Hooker found no references to it in the contemporary literature, nor did I in a search of volumes 28 to 33 (1805–1806) of *Bibliothèque Britannique*.

Hooker and Waterston (1974:72) reported the discovery of Thomson's 1804 article at the International Geological Congress in Berlin. Since then the issue of priority has been discussed by Clarke and Goldstein (1978), Marvin (1986; 2006:57), Torrens (2004), and Kichinka (2004). All agree that Thomson holds clear priority for his description and illustration of the figures but no one, except Kichinka, has argued for changing today the 200-year old name of Widmanstätten figures to "Thomson figures." Inasmuch as Thomson's articles of 1804 and 1808 failed to elicit any response from his contemporaries, he contributed nothing to the advancement of knowledge of iron meteorites in the early nineteenth century. Von Widmanstätten's prints, in contrast, clearly did inspire his colleagues to undertake new investigations of iron meteorites and to apply his name for the figures. A time-honored consensus, discussed by Twidale (2004:298), awards credit in science to the person who convinces the world, not to the first one who has an idea or makes a discovery. In any case, it would be out of the question today to reverse nearly two centuries of usage and change the name of Widmanstätten figures to Thomson figures. Such a change would bring no comfort to Thomson, and any attempt to make one would rightfully arouse the ire of partisans of von Widmanstätten. Finally, it would clutter the literature if each author were to refer to "Thomson figures (formerly called Widmanstätten figures)."

Two More Small Planets Discovered between Mars and Jupiter

The third small planet, Juno, was sighted in 1805 by Carl Friedrich Harding (1765–1834), and the fourth, Vesta, in 1807 by Wilhelm Olbers. Orbital calculations showed that all four asteroids could have diverged from a common node—a shattered planet. Olbers was not ready to propose such a source for fallen stones, but Chladni was delighted. Chladni (1805:272) wrote that as a child he had been fascinated by the large empty space between Mars and Jupiter and had predicted that a planet would be found there. Indeed, in his book of 1794, debris from a disrupted planet—although not necessarily of our own solar system—was Chladni's second choice as a source of meteor-stones.

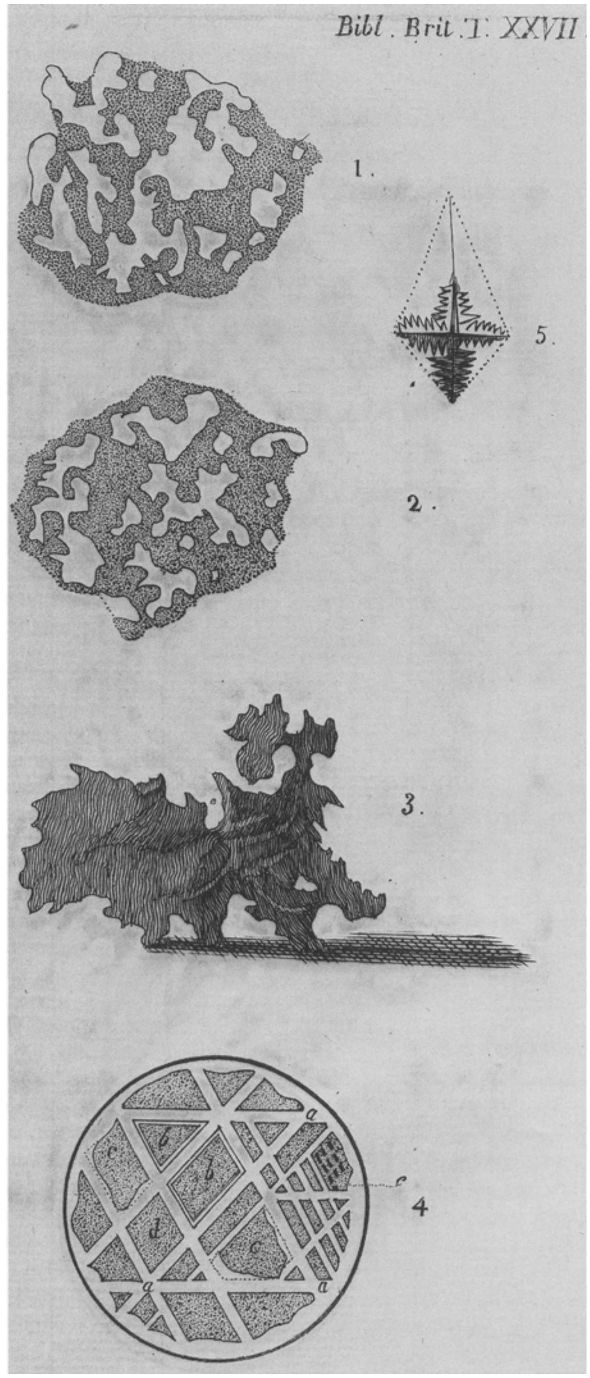


Fig. 19. William (Guglielmo) Thomson's drawings of fragments of the Pallas iron. Numbers 1 and 2 are two polished surfaces of the same sample showing peridot (white) in a matrix of NiFe (stippled). "I have drawn with a scrupulous exactitude the configuration of iron and peridot," wrote Thomson (1804:148). Number 3 is a rough, cellular fragment of the metal with no visible peridot. Number 4 is the first drawing ever made of the octahedral pattern formed by bands and fields of metallic NiFe of three different compositions. Number 5 represents the patterns formed in iron slag from a foundery. Thomson said he had severely strained his eyesight in making these drawings (From Thomson (1804), *Bibliothèque Britannique* 27:135–154, 209–229).

Pierre M. S. Bigot de Morogues: The First History of Meteoritics, 1812

In 1812, Bigot de Morogues (1776–1840), who started his career as a mineralogist and later turned gentleman farmer, published *Mémoire Historique et Physique sur la Chute des Pierres Tombées sur la Surface de la Terre à Divers Époques*, a 361-page book which qualifies as the first history of meteoritics. In his preface, Bigot acknowledged the excellent writings of Izarn and Chladni and articles in French journals as his main sources. He also informed his readers that he had no new theory of his own to offer. His book is a clearly written compendium of information on falls and finds, mineralogy, chemical analyses, and hypotheses of origin that were published up to 1812. Some critics complained that it was derivative of Izarn, and indeed it was to some extent, but Izarn finished writing his book just before the fall at L'Aigle and there were only so many original sources to consult up to that date. Bigot carried the story up through the first fall of a carbonaceous chondrite, at Alais, France, in 1806, and the fall of a chondrite at Charsonville, France, in 1810. Westrum (1978:488) justifiably calls this book the best overview of the meteorite controversy. However, it is to Bigot that we owe our negative impressions of the Royal Academy of Sciences as a group of elitists disdainfully refusing to consider the possibility of falls despite the rapidly accumulating evidence. Burke (1986:31) suggests that his attitude may reflect Bigot's resentment of aristocrats due to own lowly birth and his coming of age during the French Revolution.

METEORITE ORIGINS: FROM CHLADNI'S TIME TO THE PRESENT

Origin within the Earth-Moon System

The problem of the origin of meteorites, raised by Chladni, was not satisfactorily resolved until the latter part of the twentieth century. This issue is of such importance that we will briefly trace the main trends of thought on it from his time to our own.

The first hypotheses of meteorite origin to be abandoned, about 1805, were those that falling stones and irons were terrestrial rocks: ejected by volcanoes, transported by hurricanes, or transformed *in situ* by lightning bolts. As long as savants were unwilling to seek sources beyond the Earth-Moon system, that left a choice between an origin within the Earth's atmosphere or in volcanoes of the Moon.

Atmospheric Origin, about 1796–1860

When scientists began to take seriously the authenticity of fallen stones and irons, many of them accepted Lavoisier's assertion of 1789 that solid bodies may coagulate within the upper atmosphere. Alexander von Humboldt (1799:18) explained:

> . . . it is well known that hydrogen gas volatilizes iron. If this gas forms clouds several leagues high in the atmosphere and an electric spark sets it afire, the dissolved iron reunites in a solid mass and falls in the form of flaming balls. I believe that these facts merit to be carefully considered, before searching for other explanations.

This idea, championed in 1803 by Joséf Izarn, gained widespread support in Europe and America. The final recruit appears to have been an American, Mrs. G. (Hepsa Ely) Silliman, who wrote (1859:7):

It seems not in accordance with ascertained science to ascribe mysterious appearances on the Earth, or in its atmosphere, to causes proceeding from planets, or spheres moving in space, independent of the Earth and its system.

But, given the difficulties of accounting for the great volumes of solid matter that must instantaneously be congealed into huge solid bodies with strong similarities in textures and composition and the presence of nickel in the metals of both stones and irons, the idea of atmospheric origin finally was abandoned in the 1860s.

Lunar Volcanic Origin, about 1787–1860

When William Herschel (1787:230) reported observing four volcanic eruptions on the Moon, Lichtenberg was delighted. He wrote to Herschel that the Moon might, even now, be forming its own atmosphere and in a few centuries people might be able to discern its indistinct twilights and clouds. Other astronomers of that period who subsequently reported sighting volcanic eruptions on the Moon included the Astronomer Royal, Nevil Maskelyene (1731–1811), Jêrome de Lalande, Jean-Dominique Cassini (1748–1845), Johann Bode, Franz Zaver von Zach, and Johann Schröter (Home 1972:8).

It was but a short step from seeing lunar eruptions (or having famous astronomers see them) to believing that the eruptions ejected meteorites. Lichtenberg may have discussed this possibility with friends but he did not write about it. As we noted above, Chladni (1819:7) wrote that as soon as his book (of 1794) appeared, Lichtenberg told Professor Harding and others that reading it made him feel as though he had been hit on the head with one of the stones; he had begun to wish Chladni had not written it. Lichtenberg wrote a close equivalent to that statement in his postscript to Benzenberg of November 3, 1798. However, Chladni added that later on Lichtenberg changed his mind and wrote in his Göttingen Taschenkalender of 1797: "The Moon is an unfriendly neighbor, as he is pelting the Earth with stones."

Benzenberg (1839) used this statement, enclosed in quotation marks, on the title page of his book: *Die Sternschnuppen*, and he ascribed it to Lichtenberg's

Taschenbuch of 1797. However, while preparing a paper on Lichtenberg's ideas on the origin and evolution of the Earth, Professor Wolf von Engelhardt, (1996) failed to find any reference to the Moon as an unfriendly neighbor in any of the Taschenbuchs or other writings that Lichtenberg maintained almost up to the time of his death in 1799. Von Engelhardt (1996, personal communication) concluded that Lichtenberg never wrote about meteorites from the Moon.

When Biot (1803a) called a lunar volcanic origin of meteorites, "Laplace's hypothesis," he lent it great prestige among both scientists and the public. In England it was popularized so intensively by Thomas Young (1773–1829), the Foreign Secretary of the Royal Society, that a guidebook to Yorkshire (about 1810) described the Wold Cottage stone as a piece of the Moon (Pillinger and Pillinger 1996).

Chladni himself announced in favor of a lunar volcanic origin in 1805. He said he was persuaded to this view by the uniform textures and compositions of stones, which implied a common origin, by their abundance of unoxidized nickel-iron consistent with the Moon's lack of an atmosphere, and by their average specific gravity of 3.3 g/cc, equivalent to that of the Moon. Chladni (1805:260) wrote:

> At the present time I completely agree, that the stone and iron masses, which often fall with a fireball, are nothing other than ejecta from volcanoes on the Moon, and it is enough for me to have been the first in modern times to demonstrate in my treatise that 1) the reports of such falls were not fabrications but actual observations and 2) that these masses come from outside of the atmosphere.

These were Chladni's proudest claims ten years after the publication of his book. Notably, he no longer insisted on linking every falling body with a fireball. He must have been puzzled about falls with no reported fireballs, but at that time Chladni could not have understood that daylight falls frequently are witnessed after the terminal explosion has extinguished the fireball. Thirteen years later, Chladni (1819: 10) reversed himself and argued, once again, that the velocities of meteors in the Earth's atmosphere so far exceed those expected of bodies from the Moon that he returned to his original hypothesis of an origin in cosmic space.

Support for a lunar volcanic origin of meteorites continued until 1859 when the American astronomer, Benjamin Apthorp Gould (1824–1896), delivered the *coupe de grace*. Gould (1859:185) calculated that of each five million fragments ejected by lunar volcanos only three would be likely to enter into an orbit that would intersect with the Earth. At that rate, given the growing inventory of at least 160 meteorites that had fallen or been found by mid-century, the Moon should have visibly shrunken in size and altered in its librations and nutations, but none of this had happened. This problem, recognized by Olbers as early as 1795, had become insurmountable.

Meanwhile, J. Lawrence Smith (1818–1883), an American chemist and meteorite collector, had another idea. In a paper supporting the premise that meteorites have been projected to Earth by lunar volcanos—doubtless long extinct—he postulated that they may also have been ejected by some other disruptive force. Smith (1855:170) wrote:

> The views here advanced do not at all exclude the detachment of these bodies from the Moon by any other force than volcanic. It is useless for us to disbelieve the existence of such a force merely because we cannot conceive what that force is . . . suffice it to know that meteorites are fragments and, if so, must have been detached from the parent mass by some force.

More than 125 years were to pass before a process, namely asteroidal impacts that could accelerate lunar fragments to escape velocity, would qualify as Smith's "other disruptive force."

Asteroidal versus Interstellar Origin, about 1854–1959

Asteroidal Origin

Although questions were raised about a possible asteroidal origin of meteorites when the first four small planets were discovered in 1801–1807, no strong support for that hypothesis was voiced at that time. After 1807, no additional asteroids were found until 1845. Then a series of discoveries revealed 20 more asteroids by 1854. That year, the English scientist Robert P. Greg (1826–1906) argued that meteorites were the minute outliers of asteroids, all of which had been separated from a single planet by a tremendous cataclysm. As evidence, Gregg pointed out that asteroids, like other planets, revolve counterclockwise around the Sun in elliptical orbits, and are angular in shape rather than spherical, as shown by sudden changes in their optical reflectivity. While the hypothesis of an asteroidal origin of meteorites gained increasing attention from astronomers, geologists and mineralogists already had began to study meteorites for clues to the nature of their parent planet.

In 1847, Adolph André Boisse (1810–1896) showed that by arranging meteorites concentrically by decreasing density, with Ni irons representing a core overlain by pallasitic stony-irons that are overlain, in turn, by stony meteorites of increasingly silica-rich composition, he could produce a working model of a meteorite parent planet (Fig. 19), which often was taken as analogous to the interior of the Earth. This convinced numerous geologists that meteorites are, indeed, the debris of a shattered planet. However, once astronomers were prepared to venture beyond the Moon for sources of meteorites, the asteroidal theory met with strong competition from Chladni's old hypothesis of cosmic (interstellar) origin.

Interstellar Origin

Chladni argued for an interstellar origin of meteorites because many meteors and fireballs seemed to exceed the maximum velocity of 42 kilometers per second for bodies following elliptical orbits around the Sun. To many, a cosmic origin seemed assured after the night of January 30, 1868,

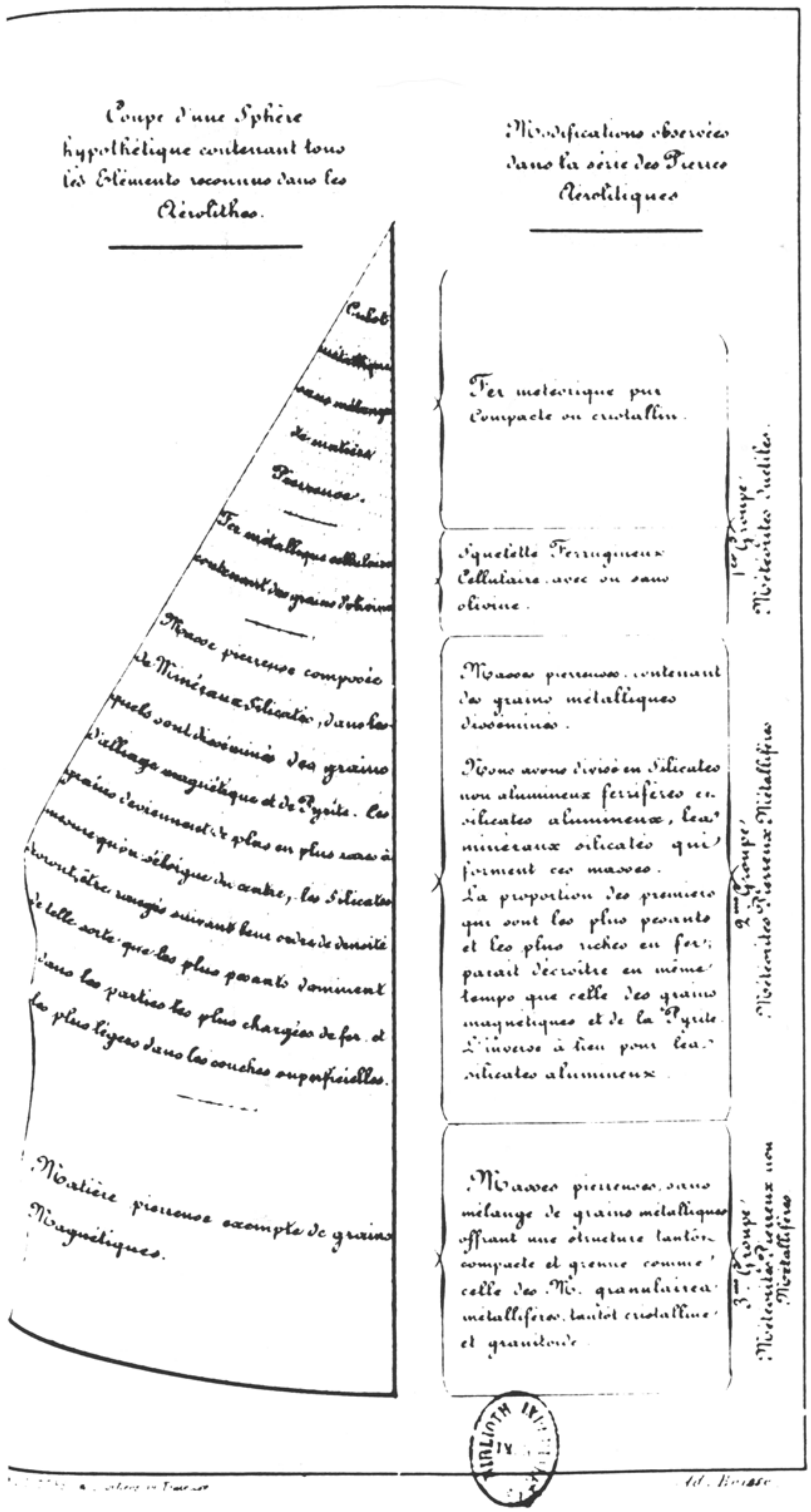


Fig. 20. The earliest cross section of a hypothetical meteorite parent planet. The concentric shells are subdivided into three main groups, which are indicated by brackets. The innermost group consists of a core of crystalline iron enveloped within a thin zone of cellular iron with or without olivine. In the second group, stony meteorites, rich in ferrous silicates and grains of NiFe, gradually give way to those with aluminous silicates and scarcer metal. The outermost group consists of achondrites. (From Boisse 1847:169).

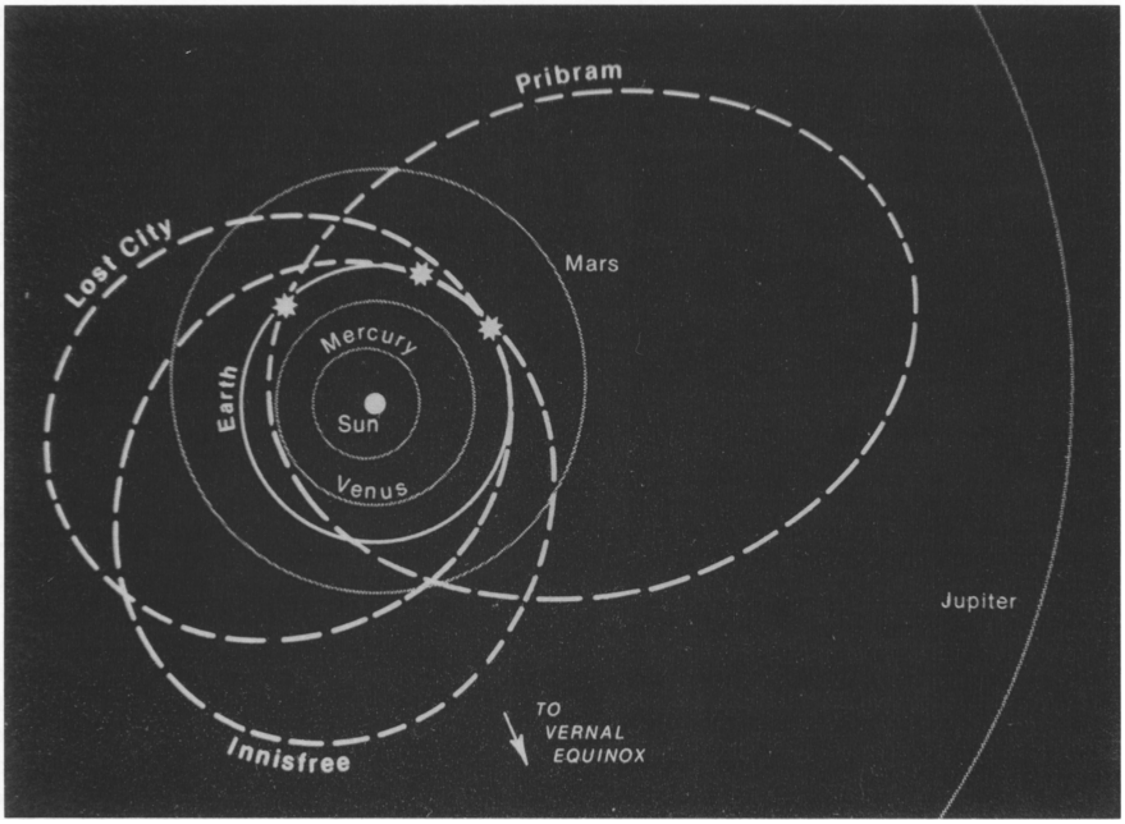


Fig. 21. The calculated orbits, projected onto the plane of the ecliptic, of the first three meteorites of which fireball trajectories were photographed simultaneously by at least two cameras. The aphelia of all three bodies lay between Mars and Jupiter. Eleven cameras photographed the fireball of the Příbram meteorite which fell in former Czechoslovakia (now Czech Republic) at 7:30 P.M. on April 8, 1959. Příbram orbited closer to Jupiter than any other known meteorite. Four cameras of the Smithsonian Prairie Network photographed the fireball of the Lost City meteorite that fell in Cherokee County, Oklahoma, at 8:14 P.M. on January 3, 1970. This was the first instance when a meteorite was found strictly as a result of photographic measurements. The Innisfree meteorite that fell in Alberta, Canada, at 7:17 P.M. on February 5, 1977, was discovered as a result of photographs taken by the Meteorite Observation and Recovery Program of the National Research Council of Canada. Příbram's orbit was the only one known to reach the outer fringes of the asteroid belt until April 6, 2002, when that of the Neuschwanstein meteorite, which fell in southern Bavaria, proved to be identical to it. (Diagram courtesy of I. Halliday and *Sky & Telescope* 1977:339.)

when a great shower of stones fell at Pułtusk in Poland. By sheer chance, 37 persons, including an amateur astronomer at Breslau (now Wrocław) and one at Danzig (now Gdańsk), were observing that part of the sky. Calculations indicated that the Pułtusk meteorite was traveling at a hyperbolic velocity of 56 kilometers per second—hence it appeared to have entered the solar system from interstellar space.

Observations of hyperbolic velocities continued well into the1950s. Ernst J. Öpik (1893–1985), the Estonian astronomer, declared in 1935 that the interstellar origin of meteorites could be taken for granted (Paneth 1940:12). And in 1937 Cuno Hoffmeister, who had published a catalog showing hyperbolic orbits for 79% of well-observed bright meteors and fireballs, stated that the interstellar origin of meteorites was well established. In 1953, Lincoln LaPaz (1897–1985), the founder and first director of the Institute of Meteoritics at the University of New Mexico, listed as his most important research contribution of the past 20 years the verification by new, independent, non-visual (radar) methods the existence of meteorites moving in hyperbolic orbits with respect to the Sun. LaPaz argued that meteorites are from two sources: planetary and galactic (Leonard 1953:72).

Other astronomers believed that the high velocities reported for meteors and fireballs must reflect a systematic error. Compilations of long-term records such as those begun by Gregg in the 1850s were showing that a great majority of meteorite falls occur between noon and midnight, as if bodies orbiting the Sun were overtaking the Earth. In the 1930s and 1940s, painstaking photographic studies of meteors, taken by at least two cameras simultaneously, by Professors Fred L. Whipple (1906–2004) and his colleagues at the Harvard College Observatory, and by Professor C. C. Wylie at the University of Iowa, showed elliptical solutions for the orbits of all the well-documented meteors and fireballs they measured. Öpik disputed their findings until 1959 when he abandoned the idea of hyperbolic orbits on his own evidence and wrote to Whipple apologizing for his previous criticisms (Marvin 1993:277). At about the same time, a recalculation of the trajectory of the Pułtusk body showed that it, too, followed an elliptical orbit, which made it a member of the solar system.

In 1959 April 7, the Příbram fireball passed through an area of sky being monitored by several cameras of the European Fireball Network and dropped stones near Prague, Czech Republic. Calculations showed that the meteoroid had followed an elliptical orbit with aphelion at the far outer fringes of the asteroid belt (Fig. 21). Forty-three years later to the day, on April 6, 2002, a brilliant fireball was seen and photographed over much of central Europe. Calculations showed its orbit to be identical with that of Příbram! Indeed, the matching was so perfect that its chances of being coincidental were estimated at no better than 1:100,000. This observation reinvigorated the idea of meteorite streams, which had been partly abandoned, and led to the prediction that if stones were found, they would be ordinary H5 chondrites like Příbram. A stone soon was found, at Neuschwanstein, near the famous castle in southern Bavaria. A short time later a second stone was found, on the Austrian side of the border. The area where these stones lay is not far from the Příbram site of fall. But instead of being H5 chondrites, the Neuschwanstein stones are enstatite chondrites. Furthermore, Příbram has orbited through space being bombarded by cosmic rays for about 19 million years; Neuschwanstein has a cosmic ray exposure age of about 48 million years (Russell 2003:A202). Their differences in composition and cosmic ray histories make it difficult to envision an origin in the same parent body.

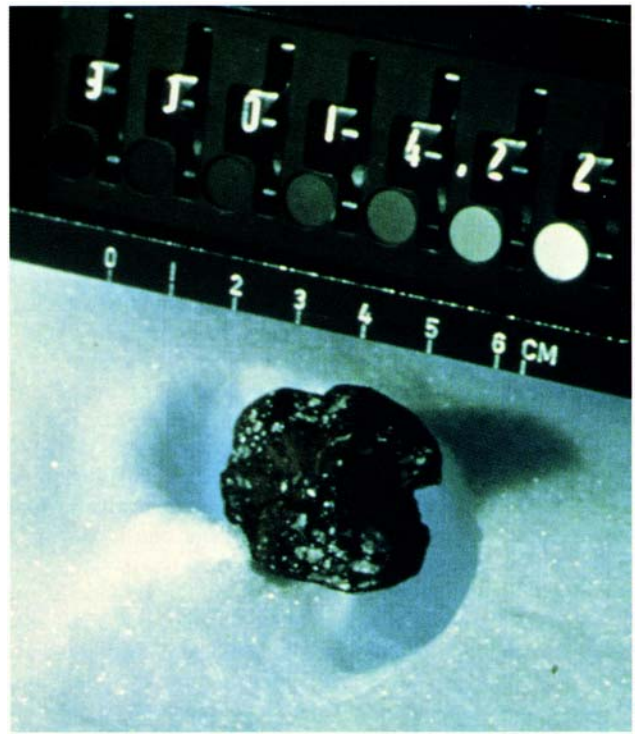


Fig. 22. Lying on the ice sheet at a remote site west of the Allan Hills of Antarctica, this 32 g stone, about the size of an apricot, was collected by a U.S. search team on January 25, 1982. It proved to be the first sample of the lunar crust to be identified on the Earth and opened a new era in meteoritics and planetary science. (The handheld numbering device has a 6 cm scale; NASA photograph.)

Meteorites from Asteroids and Other Planets

For the past half century, all scientists have agreed that meteorites are fragments of planets—but which ones? When diamonds were discovered in iron meteorites in the late 1880s and early 1890s, they were taken as tangible evidence that meteorites originate in a large planet with high core pressures. In the 1950s, Harold Urey (1893–1981), the distinguished nobelist in chemistry who had turned his attention to planetary science, argued that formation of diamonds would require high gravitational pressures in bodies at least as large as the Moon. A few years later, however, Urey and others calculated that a molten iron core in a Moon-sized planet could not have solidified in the entire 4.5-billion-year age of the solar system. Subsequent cooling-rate calculations showed that Widmanstätten figures could form only in small bodies less than 250 kilometers in diameter. The contradictory demands for large versus small parent bodies were not resolved until 1960, when scientists at the General Electric Company succeeded in creating diamonds in shock wave experiments (DeCarli and Jamieson 1961). The resulting clumps of angstrom-sized carbonado diamonds resembled those in the Cañon Diablo iron and led to the conclusion that meteoritic diamonds result from shock pressures incurred during collisions with the Earth or with other bodies in space (e.g. Lipschutz and Anders 1961). Once the mineralogical requirements for a large parent planet were removed, several lines of evidence led to the currently accepted belief that asteroids originated as small bodies and meteorites are collisional fragments of asteroids. Since 1981, however, two other planetary bodies have been identified as sources of meteorites.

Meteorites from the Moon and Mars

In January 1982, the first meteorite from the Moon was discovered on the Antarctic ice sheet (Fig. 22). Scientists from seventeen laboratories around the world agreed on its lunar origin when they found close matches between its mineralogical, chemical, and isotopic compositions with lunar highland samples collected in 1972 during the Apollo 16 mission. The meteorite was not, however, a sample of volcanic ejecta; it had been projected from the surface of the Moon by the impact of an asteroidal fragment that accelerated it into an Earth-crossing orbit. Were he with us today, J. Lawrence Smith might be proud to claim impact as the unknown force he intuitively felt might exist for projecting crustal samples from the Moon to Earth.

By the fall of 2006, one hundred and fourteen fragments of forty-eight meteorites from the Moon had been collected on the Earth—fifteen from Antarctica, one from Australia, and the rest from other continents—chiefly the hot deserts of Africa and Oman. About half of the meteorites consist of anorthositic breccias from the lunar highlands, seven are mare basalts, and the others breccias of mixed rocks. The single sample from Australia reportedly contains a small component of lunar KREEP (a type of rock found at the Apollo 14 site, enriched in potassium, rare earth elements, and phosphorus).

The finding of lunar meteorites prompted a serious reconsideration of possible meteorites from Mars. A Martian source had been suggested in 1979 when crystallization ages of only 1.3 billion years, indicative of an origin within a large, well-insulated body, were measured on certain igneous achondrites (Walker *et al*. 1979). But at that time Martian meteorites were in disfavor on statistical and dynamical grounds: if we had no meteorites from the nearby Moon we could not expect to find them from Mars; furthermore, the Martian escape velocity (5.5 km s^{-1}) would require so energetic an impact that any escaping samples would be crushed or shocked beyond recognition. But in 1982 these hypotheses were confronted with hard evidence. That year, the first Martian meteorite was confirmed as such when analyses of an igneous achondrite from Antarctica showed it to be similar in bulk composition and rare gas content to the Martian soil and atmosphere analyzed *in situ* by the Viking Landers on Mars in 1976 (e.g., McSween 1994). Today, we recognize at least 34 meteorites from Mars—ten found in Antarctica and 24 on other continents. All but one of them are relatively youthful crystalline rocks from volcanic terrains; the other one, Allan Hills (ALH) 84001, is a sample of deep-seated pyroxenite from the 4.5-billion-year-old crust of Mars. This is the Martian meteorite in which evidences of fossils were reported in 1996 by David McKay, at the Johnson Space Center in Houston, and eight coauthors, but at present no signs of biogenic constituents have been confirmed.

Planetary Meteorites: Cosmic Grains

Today, meteorites are universally accepted as debris from collisions of asteroids with each other and with the Moon, and Mars. Millimeter-sized micrometeorites are believed to be grains released by the sublimation of ices in comet nuclei. Although all of these bodies are members of the solar system, isotopic anomalies have led to the discovery that certain meteorites contain minute grains, including silicon carbide, diamonds, corundum, and several rare species from interstellar sources older than the solar system (e.g., Huss 1988; Anders and Zinner 1993). This unpredicted circumstance indicates that the primeval solar nebula did not consist of a homogeneous mix of dust and gas. Various unvolatilized components, ejected by supernovae or red giant stars, entered the cloud and accreted into the growing planetary bodies 4.6 billion years ago. Although Chladni had no such an idea in mind, he surely would be interested to learn that although meteorites themselves belong to the solar family, some of them do, indeed, carry to Earth particles from interstellar space.

PREMATURE IDEAS IN METEORITICS

It may come as a surprise to most meteoriticists to learn that Chladni was not the first person to write that the Pallas iron fell from the sky, nor was he the first to report the fall of the Hraschina irons. Scientists in all fields, perusing old documents, often discover intriguingly "modern" ideas written in the past and forgotten. Very often the ideas were ignored in their time because they were premature. Perhaps the best definition of premature ideas or discoveries was offered by Gunther Stent (1978:99), a professor of microbiology at the University of California at Berkeley:

A discovery is premature if its implications cannot be connected by a series of simple, logical steps to canonical, or generally accepted knowledge.

Paneth (1940:8) wrote much the same thing:

> . . . if the light of historical studies is thrown on 'new' scientific conceptions, more frequently than not they bear out the truth of Goethe's saying: 'Every bright thought has already occurred to somebody; the whole point is to think it again.'

To better evaluate Chladni's contributions to the beginnings of meteoritics, it may be helpful to examine some examples of prematurity in this field.

Two Treatises by Franz Güssmann, 1785 and 1803

In 1785, nine years before Chladni's book appeared, Franz Güssmann (1741–1806), whom we met earlier, published a physico-mineralogical treatise, *Lithophylacium Mitisianum*, a 632-page systematic mineralogy beginning with the native elements. In the section on *Ferrum Nativum*, Güssman (1875:127) described the mass seen by Pallas in Siberia. Through his access to the archives of the Imperial Cabinet, Güssmann also described the fall of the irons at Hraschina, five years before Andreas Stütz published his account from the same manuscript. Güssman mentioned the dazzling fireball and explosions and said that the sworn testimony of the seven witnesses seemed entirely credible. He theorized that these irons had been melted in the Earth by stupendous electric fires that launched them into the sky as a mortar throws a bomb. Despite Güssmann's position in the heart of scientific circles in Vienna, his ideas on fallen irons immediately passed into limbo; he was not cited by Stütz or Chaldni. In 1803, Güssmann wrote a second book, *Über die Steinregen*, to prove the mathematical impossibility that falling bodies could have come from the Moon. In it, he protested the neglect of his earlier work.

On November 2, 1803, one Dr. DeCarro, who acted for many years as the Vienna correspondent to the *Bibliothèque*

Britannique, wrote to Pictet that the subject of fallen stones had excited the curiosity of several savants in Vienna. For example, he said, there just appeared a work by the excellent mathematician Güssmann. DeCarro (1803:289) sent Pictet a copy of Güssmann's *Steinregen* and a reference to his *Lithophylacium*. Güssmann, he said, theorized that the irons originated as molten masses that had been thrown into the sky and fallen back in fireballs. With respect to Güssmann's "markedly original" hypothesis, DeCarro raised two questions: first, how is it that, given the numbers of people who have seen these flaming bodies fall, no one has seen them lift up from the Earth; secondly, how, by this process, can we explain the presence of such a rare metal as nickel which is found in almost all these products?

Decades later, in 1859, Wilhelm Karl Haidinger, director of the Imperial Natural History Cabinet in Vienna, wrote that he first learned of Güssmann's treatise of 1785 from two notes that his predecessor, Paul Maria Partsch (1791–1856), had written in works he found in the archives. Partsch's first note appeared in the margin of page 245 of Chladni's book *Über Feuer-Meteore* (1819) where Chladni discussed the fall at Hraschina. The second was on a manuscript page from Güssmann's *Lithophylacium Mitisianum* where Partsch wrote (in Haidinger 1859:362):

> He [Güssmann] connected fiery meteors with falling meteorites earlier than Chladni. There was found in his book also a discussion of the Agram [Hraschina] mass. This surely is the first printed notice (unless an earlier published report exists).

Haidinger remarked that Chladni apparently knew of neither the one nor the other; referring to Güssmann's linking of meteorites with fiery meteors and Güssmann's description of the fall at Agram.

In our day it is difficult to understand why Güssmann's books were so completely ignored, particularly since he proposed a terrestrial origin for native irons and linked them with fireballs. Clearly, his ideas that the Krasnojarsk and Hraschina irons fell from the sky were premature when he published them in 1785. That is indicated by the fact that five years later Stütz denied the "alleged" Hraschina and Eichstädt falls and rejected the reports as due to the credulity of country folk. Perhaps, Stütz chose not to dignify the idea of falls with an earlier citation. Chladni, who wrote about falls of the Pallas and Hraschina irons only nine years after Güssmann did, would have totally rejected Güssmann's explanation of them but, in his effort to cite as many references as possible on falls, it seems unlikely that he would have skipped Güssmann's work if he had been aware of it. Evidently, he found no copy in the library at Göttingen.

The "Firsts" of Guglielmo (William) Thomson, 1794 and 1804

As noted above, Thomson performed the first magnetic separation of iron grains from stones and wrote the first mineralogical descriptions of fallen stones (from Siena in 1794). He was the first to propose a name (soldanite) for the new type of rock he observed in fallen stones, and the first scholar to suggest in print the possibility of their lunar volcanic origin. Thomson also was the first person to polish and etch meteoritic metal (of the Pallas iron), to recognize that the pattern he saw was formed by three metals of differing compositions arranged in an octahedral structure, and to publish drawings of this pattern in a well established journal. One friend, Soldani reprinted his article and duplicated his picture four years later in the Atti of Siena. For all that, William Thomson remained virtually unknown to meteoriticists until recent years when a number of scientists began to document his contributions.

Ironmasses by Ernst Chladni, 1794

Prematurity also applies to Chladni's own first book, in which his hypotheses of fallen stones and irons of cosmic origin contradicted the canonical knowledge of his day. Fortunately, his hypothesis of falls remained premature for only two months when the shower of stones at Siena began the dramatic series of events that led to his vindication.

However, besides being premature, Chladni's reliance on eyewitness reports was a flawed approach, aspects of which would be as unacceptable today as it was to his contemporaries. As we have seen, Chladni repeated story after story that fallen stones filled the air with sulphurous fumes and/or were too hot to touch. For the past half-century or more, few, if any, witnesses have reported sulphurous fumes, but today, every curator still hears stories that "fallen" stones or irons were hot to the touch (even when the proffered specimens are fragments of bog iron ore, limonite concretions, or slag). Why did meteorites lose their smell? queried Sears (1974:299). He suggested that in earlier times when everyone was aware of biblical "fire and brimstone" they reported both; now that brimstone is out of fashion, they still report fiery hot meteorites. It seems that eyewitness reports tend to be biased in favor of what people expect would fall from a fireball.

In fact, meteorites do not strike the Earth scorching hot. They are enveloped in fireballs for only a few seconds, and, after incandescence ceases, the bodies fall through the air for several miles. Buchwald (1975, I:8) compared the process to heating a massive lump of cold iron with oxyacetylene torches for a few seconds then changing to forced cooling with jet air streams. Freshly fallen meteorites are either cold or, at most, slightly warm. Thus, meteoriticists of the twenty-first century frequently find themselves harboring attitudes closer to those of the Abbé Stütz in 1790 than to those of Chladni: how is it that people say they found a meteorite too hot to handle when such fairy tales violate the laws of physics? Chladni's reliance on historical reports, however convincing they were to his lawyer's ear, worked surprising well in view of the pitfalls in this method.

Catastrophic Impacts

Not all meteorites lose their cosmic velocity during flight. Today we are well aware that large bodies sometimes plunge into the Earth at cosmic velocities and excavate craters. In rare instances, hypervelocity impacts give rise to worldwide geological and biological catastrophies. The importance and ubiquity of meteorite impact as a geological process of global importance has become widely recognized only since the opening of the Space Age in the late 1950s. There is, however, a long record of premature hypotheses on this subject.

Well into the 1840s, Professor Benjamin Silliman at Yale University expounded the hypothesis that meteorites fall from Earth-orbiting comets which never plunge to Earth. In public lectures, which must have been spellbinding, Silliman (in Burke 1986:66) would declare:

> May they [the comets] not one day come down entirely? Shall we desire it? They might sweep away cities and mountains—deeply scar the earth and rear from their own ruins colossal monuments of the great catastrophe.

At present, when similar rhetoric has become commonplace, should we credit Benjamin Silliman as the founder of the concept of megaimpacts? We cannot do so because Silliman had predecessors. As examples, we may consider one such visionary (there were others) in each of the last four centuries: in 1752 Pierre de Maupertuis (1698–1759) wrote that comets striking the Earth might have caused vast disruptions, possibly with wholesale extinctions of living things due to heat, poisoned air, and acidified water. In 1696 William Whiston (1667–1752) described comet impact as the predominant factor in shaping the early Earth: tilting its axis, starting it rotating, cracking the crust to release the flood, while its tail condensed to form torrential rains. In the twentieth century, Harvey H. Nininger (1887–1986) wrote in 1942 that impacts of earth-crossing asteroids like Hermes, which passed us within a few 100,000 miles in October 1937, might well cause geological revolutions, violent climatic changes, and the cataclysmic destruction of species. All of these prophets spoke prematurely when their ideas could not be reconciled with contemporary knowledge. Although Nininger wrote his paper at a time when meteorite impact craters had been validated, geologists still thought of them as natural curiosities of no importance to global geology.

Not until 1980 when the group of scientists led by Luis Alvarez (1911–1988), at the University of California at Berkeley, presented geochemical evidence that a megaimpact at the end of the Cretaceous period had deposited excess iridium in the thin layer of clay at the Cretaceous-Tertiary boundary worldwide, and may have triggered the massive extinctions of dinosaurs and other biota, did large scale research on this subject begin. Later in that decade, a consensus began to form that a collision with a Mars-sized planetoid disrupted the early Earth, tilted its axis, and spun off the debris that aggregated to form the Moon (e.g., Cameron 1986). After 200 years, the idea of collisions of large and small planetary bodies with the Earth have begun to occupy the forefront of scientific thinking. Numerous surveys are being conducted at observatories in the United States and other countries with the aim of detecting the approach of Near Earth Objects—asteroids or comets with lead times sufficient to issue warnings or, if possible, to devise plans to alter their courses. The Minor Planet Bureau of the Smithsonian Astrophysical Observatory has established its NEO Confirmation Page for rapid exchanges of observations by scientists and amateurs worldwide. It may be accessed at http://cfa-www.harvard.edu/iau/NEO/ToConfirm.html.

Our need for continual observations gained momentum in July 1994 when we all watched the dramatic crashes, relayed to us by Hubble Space Telescope, of more than 20 fragments of comet Shoemaker-Levy 9 into Jupiter.

CONCLUSIONS: THE FOUNDING OF METEORITICS

Chladni's Views on the New Science: 1809

Chladni's own observations on the founding of meteoritics appeared in the preface to a French version of his *Traité d'Acoustique* (1809), which he translated and revised from a German version of 1802 during a long stay in Paris at the invitation of Laplace. During this visit, Napoleon Bonaparte awarded an honorarium of 6,000 francs to Chladni for his discoveries in acoustics. Chladni wrote (1809:9):

> At the beginning some did not agree with me; some German critics even supposed that I had not advanced these ideas seriously but with the intention, a bit mischievous, to see which side philosophers would take, and how far the credulity of some persons would go . . . In France . . . most did not even believe in the possibility of a fall of stones until the Memoir by Howard in 1802, and in 1803 the fall of the stones at L'Aigle, followed by the report by M. Biot, proving that my book was not a flight of fancy.

Thus, Chladni himself listed Howard's memoir, the fall at L'Aigle, and Biot's report as factors that played crucial roles in the acceptance of his book.

To Chladni's own list we must add the truly extraordinary series of observed falls over the turn of the 19th century. Chladni had compiled reports of only 18 well-described falls from ancient times to the fall at Eichstädt in 1785. Suddenly, five witnessed and widely publicized falls took place in nine years, from the fall at Barbotan in 1790 to that in Benares in 1798—more than one every two years. Without the falls, there would have been no chemical analyses, and it was the chemical work that led to acceptance of falls as authentic natural phenomena a year *before* the fall occurred at L'Aigle.

In seeking answers to the questions raised at the beginning of this paper we have found that the early reviews of Chladni's book in Germany were negative. Chladni had relied too heavily on folk tales to persuade his contemporaries of the existence of falling bodies, and he violated the rules of Newtonian physics by postulating their origin in cosmic space. It seems unlikely that any of his contemporaries changed their minds on these subjects simply as a result of reading Chladni's book. Therefore, it appears that if neither a series of witnessed falls nor chemical analyses had taken place for half a century after Chladni's book appeared, meteoritics would have languished for half a century. On the other hand, given the activity in the skies and in the laboratories, meteoritics would have been established as a new field of inquiry in 1802, even if Chladni had not written his book.

But Chladni did write his book. Possessing no positive evidence for falling stones and irons, he had proposed his radical hypotheses at a time when they ran counter to the accepted laws of physics, and when witnesses to actual falls were withholding their evidence for fear of ridicule. When events forced his contemporaries to accept meteorite falls, they reread his book and referred to it. Without question, Chladni was a leader in the founding of meteoritics.

In addition to Chladni, our pantheon of the founding fathers of meteoritics must include Georg C. Lichtenberg, whom Chladni credited with providing him with the background knowledge and the inspiration to investigate fireballs and falling masses; the Abbé Ambrogio Soldani, who gathered information and stones at Siena and published the first scholarly treatise on a meteorite fall; Marc-Auguste Pictet, who co-founded a new journal that welcomed letters on meteorites and served as an international center of communications during the controversial formative years of the science; Sir Joseph Banks, who saw the need for chemical analyses of fallen stones and predicted that the results would open a new field of inquiry; Edward C. Howard, who took up Banks's challenge of analyzing "the bodies of fiery meteors" and made the extra effort to assemble a significant number of samples of stones and "native irons"; and Jacques-Louis de Bournon, who saw the necessity of separating stones for analysis into their main components, thereby concentrating the metal grains that made possible Howard's discovery of nickel that linked the stones with the irons.

As often is true, a certain amount of good luck contributed significantly to the founding of meteoritics. Certainly, the fall of stones at Siena, just two months after Chladni's book appeared, was a stroke of good fortune. The large number of witnesses prompted leading scholars in Italy to make serious investigations that were passed along to English natural historians, who experienced their own fall at Wold Cottage the following year. The coincidental eruption of Mt. Vesuvius added confusion to questions of meteorite origins for years to come but did not delay acceptance of falling stones.

Also very fortunate was the fact that all of the stones analyzed by Howard and de Bournon happened to be ordinary chondrites, and that the witnessed falls occurred at just the time when recent advances in chemistry made possible quantitative determinations of silica, magnesia, lime, and nickel. Had their samples included achondrites, with neither chondrules nor nickel-iron, their results would have been far less convincing.

Chladni continued to write and to lecture on meteorites throughout his lifetime. Chladni also collected meteorites. Ultimately, he acquired pieces of 31 stones and 10 irons—the largest private meteorite collection of the early 19th century. Despite his straightened circumstances, Chladni did not sell his meteorites. A man of great integrity, he willed them to the Mineralogical Museum of the newly founded Humboldt University of Berlin. In 1994, in celebration of the 200th anniversary year of his book, a new purchase by the university brought the total inventory of "The Old Chladni Collection" to 500 meteorites.

Recognition of a special kind was accorded to Chladni in 1993 when a new phosphate mineral [$Na_2CaMg_7(PO_4)_6$] was named chladniite in his honor. It was discovered in the Carleton iron meteorite from Texas and described by a group of investigators led by Timothy J. McCoy, then at the University of Hawaii. Assuredly, Chladni would be greatly pleased with this type of commemoration 200 years after the publication of his *Ironmasses*.

Acknowledgments–In my search for primary sources on this subject, I am much indebted to the writings of Günter Hoppe and Wolfgang Czegka on Chladni, James Burke on the history of meteoritics, Albert V. Carozzi on the great debates, and Derek Sears on the early chemical work on meteorites. I have made constant use of the facsimile of Chladni's book of 1794 with an introduction by John Wasson, who presented a copy to all participants of the Meteoritical Society meeting in Los Angeles in 1974. I wish to thank the librarians at the Harvard-Smithsonian Center for Astrophysics who searched out and obtained copies for me of several books and papers that are very difficult to find. I also thank the librarians at the Dibner Library of the Smithsonian Institution and the Houghton Library of Harvard University, who provided me with photocopies of key passages and granted permission to publish prints from their rare book collections; and the librarian of the Deutschen Staatsbibliothek in Berlin for a print and permission to publish the portrait of Chladni in Fig. 1. I thank Roy S. Clarke, Jr. and Linda Schramm of the Division of Meteorites of the Smithsonian Institution's National Museum of Natural History for providing me with rare materials from the Paneth Collection of reprints; Günter Hoppe for sending me a copy of his invaluable book on Chladni; Wolfgang Czegka for reprints of his articles on Chladni; L. Lindner for sending me Haidinger's paper of 1859 "for brushing up on my German;" A. Hildebrand for sending me the *Essay de Cosmologie* by Maupertuis; and Jörn Koblitz for a reprint of the paper by Carozzi and other important articles. I thank Monty Robson of the John J. McCarthy Observatory at New Milford, Connecticut, for giving me the NET address of the relevant Thomas Jefferson papers in the Library of Congress. I greatly appreciate much help from my husband, Tom Marvin, in translating French and German and reorganizing and proofing my original manuscript, and the many helpful suggestions I received for improving that paper from Roy S. Clarke, Jr., Howard Plotkin, and Derek W. G. Sears. I acknowledge with thanks the support I have received from the Smithsonian Institution's Research Opportunities Fund and from NASA Grant NAGW-3438.

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NOTES

1. "Meteoritics" is used herein to denote "studies of meteorites;" this covers the whole range of meanings from Chladni's initial efforts to the current interdisciplinary science. Usages of familiar terms are difficult to dispense with in writings on history. For example, the words "scientist" and "physicist" were not invented until the 1830s, but I have applied both of them to earlier savants and natural philosophers.

2. The reference commonly cited for this new knowledge is Jussieu (1723). In a short note to the Royal Academy, Anton-Laurent de Jussieu (1682–1758), a botanist and paleontologist in Paris, wrote that he had examples of stone implements, resembling so-called lightning stones, from the Caribbean islands and Canada, which were made by native peoples who patiently rubbed stones against stones. Inasmuch as Europeans had been traveling since the 1400s in Africa, the South Pacific, and the Americas, 1723 would seem to be an astonishingly late date for this fact to become known.

3. Chladni may have found his ideas of new worlds aggregated from the wreckage of old ones in the work of his older contemporary Emmanuel Kant (1724–1804), with whom, incidentally, he shared the German publisher, Johann Friedrich Hartknoch, in Riga, then a part of Russia.

4. Lavoisier was not involved in the second investigation because he was on a long tour of the Chalons region carrying out his activities as a tax farmer (Smeaton 1957). Burke (1986:27) questioned whether Lavoisier's tax-farming duties kept him away from the laboratory during the analysis of the Lucé stone, but they did not. Lavoisier's appointment began in May, the month after he read the report on Lucé to the academy. For his appointment as a tax farmer, Lavoisier ultimately paid with his life at the guillotine.

5. A subsequent calculation showed that, to reach Siena, ejecta launched from Mt. Vesuvius at the most favorable angle of 45° must follow a parabola 20 times the height of Mt. Blanc with a force nine times that of a cannon ball. (Anonymous note in *Bibliothèque Britannique* 1:405, 1796.)

6. Sowerby inserted a special section on Wold Cottage, with pages numbered 1*–19*, ahead of page 1 at the beginning of his volume 2.

7. Southey was Poet Laureate of England from 1818–1843.

8. This was the stone of which von Born had written that some credulous people claimed the stone had fallen in a thunderstorm on July 3, 1753; the fact that he kept the stone in his own collection casts serious doubt on the story told by Paneth (1940:128) that "the newly appointed curator of the Imperial Collections at Vienna, I. von Born, discovered a drawer labeled "Stones fallen from Heaven" and, trained in the new school of thought, with a scornful laugh ordered their removal."

9. Apparently, this was issued as a booklet, of which I have been unable to obtain a copy.

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