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Domenico Troili (1766): "*The true cause of the fall of a stone in Albereto is a subterranean explosion that hurled the stone skyward*"

URSULA B. MARVIN* AND MARIO L. COSMO

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02138, USA
*Correspondence author's e-mail address: umarvin@cfa.harvard.edu

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Abstract–In mid-July, 1766, a stone fell at Villa Albareto near Modena in northern Italy. A sudden explosion like a cannon shot followed by fierce whistling sounds frightened people over a wide area. Some saw a fiery body falling from the sky; others said it was dark and smoky. The ground shook when the stone plunged into the soil making a hole nearly a meter deep. The Abbé Domenico Troili collected eyewitness reports, examined the stone, and reported the presence of marchesita, an old name for pyrite. A century later, this mineral, which proved to be iron sulfide (FeS), was named "troilite" in his honor. Troili's description is unquestionably that of a meteorite fall, and therefore some scientists have argued that it is Troili, rather than Ernst F. F. Chladni, to whom we should give credit as the first person to record the fall of a stone from space. However, Troili, himself, had no such an idea; he wrote that a subterranean explosion had hurled the stone high into the sky from a vent in the Earth. He stoutly defended this explanation against his opponents, including the Bishop of Modena, who believed that the stone had been hurled aloft by a bolt of lightning. Both hypotheses reflect a conviction, held well into the nineteenth century, that any rocky objects that fall from the sky must originate on the Earth or in the atmosphere. In 1794, Chladni calculated that meteors and meteoritic fireballs course down the sky at such extremely high velocities that the bodies forming them must originate in space. He listed all the falls that he found credible in historic records. Partly through his efforts, meteorites had gained widespread acceptance by 1803, but the idea of their origin in space had not. For the next half century many scientists continued to argue that meteorites either consolidate in the upper atmosphere or are ejected by volcanoes on the Moon. Recent efforts to transfer honors from Chladni to Troili for being the first to describe meteorites as bodies falling from space are unwarranted.

THE FALL OF THE STONE

One afternoon in July, 1766, a stone fell from the sky at Villa Albareto (modern spelling), a little more than 1 km east of Modena in northern Italy (44°39' N, 11°1' E). The phenomena accompanying the fall were seen and heard over a wide area. Immediately after the event, the Jesuit Father Domenico Troili (1722–1792), custodian of the library of the ruling family of Este in Modena, collected eyewitness reports, examined the stone, and puzzled over its mode of origin. Two months later, in September, 1766, Troili published a 120-page book entitled *About the Fall of a Stone from the Air, Explanation* (Fig. 1).

Troili reported that on the afternoon of the fall the sky was serene at Villa Albareto but dark and cloudy over the distant mountains to the west and the Po valley to the north, where there were frequent flashes of lightning and peals of thunder. Suddenly, about five o'clock, while laborers were still at work in the fields, a tremendous explosion rang out like the firing of a cannon. Fierce whistling sounds followed, like those accompanying the passage of a cannon ball through the air. Presently, several terrified bystanders saw a body falling to Earth—some said it was fiery, others said it looked dark and was emitting smoke. The body struck the Earth with such force that it shook the ground. Two persons clung to branches of trees to stay upright; a cow was knocked off its feet. The body came to rest in a hole nearly a meter deep.

Troili wrote that the stone at the bottom of the hole felt warm to the touch and that the odors of sulfur and bitumen filled the air. Today we are likely to dismiss these reports because meteoritic fireballs burn out high in the sky after only a few seconds of flight, releasing the incoming bodies to fall through miles of cooling atmosphere. Stony meteorites contain no bitumen and not enough sulfur to fill the air with fumes. Nevertheless, Troili's account is clearly that of the fall of a stony meteorite, which, he hastened to add, was immediately hacked to pieces by the spectators who carried fragments to all parts of the town. Similar fates have befallen many meteorites, which have been used as medicine, or fetishes, or objects of reverence.

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DELLA CADUTA
DI UN SASSO
DALL' ARIA
RAGIONAMENTO
DEDICATO
ALLE ALTEZZE SERENISSIME
DI
BENEDETTA,
ED
AMALIA
PRINCIPESSE DI MODENA
DA
DOMENICO TROILI
Della Compagnia di Gesù.

IN MODENA MDCCLXVI.
Per gli Eredi di Bartolomeo Soliani Stamp. Ducali.
Con licenza de' Superiori.

FIG. 1. The title page of Domenico Troili's 120-page book of 1766; *About the Fall of a Stone from the Air, Explanation, Dedicated to Their Most Serene Highnesses, Benedetta and Amalia, Princesses of Modena, by Domenico Troili, of the Company of Jesus.* (By permission of the Houghton Library of Harvard University.)

A well-documented instance occurred in 1492 at Ensisheim in Alsace, where the townspeople struck pieces from a black, 300 pound stone that fell nearby until the chief magistrate forbade it. By his action he saved most of the earliest witnessed meteorite fall in the West from which pieces still are preserved (Marvin, 1992).

Troili described the stone as extremely heavy, magnetic, roughly triangular in shape, and covered with a dark crust that appeared to have been burned by fire. He estimated that the entire stone, before being broken up, would have weighed ~25 pounds (~12 kg). Fortunately, Troili himself obtained pieces of the stone which he described as looking like sandstone with steely glints scattered through it. Under a microscope he saw that many of the shiny particles were metallic iron but some were bronzy grains that he called "marchesita", an old name inherited from Arab scientists for pyrite. Troili concluded that the stone consisted of an accumulation of particles of earth, sand, marchesita, and iron.

DEBATES ABOUT THE ORIGIN OF THE STONE

The fall of the stone stirred a vigorous debate in Albareto and Modena. In the introduction to his book Troili pointed out that strong differences arose between those using non-scientific ("superstitious") and those using "scientific" arguments about the nature and origin of the stone. Troili took it upon himself to settle the dispute and to provide the public as well as the scientific community with an explanation based on natural causes. After reviewing the details of the event, Troili ascribed the stone to explosive volcanism, which was the most familiar and efficient process then known of ejecting rocks into the sky. This was the *Explanation* he referred to in his title. After discussing the problem for more than 100 pages, Troili wrote (Fig. 2):

> ...the true cause of the fall of a stone in Albereto in the middle of July in 1766 is a subterranean explosion that hurled the stone skyward.

Troili supported this statement with the following four propositions, each of which he discussed in detail, thinking that these would make his conclusion irrefutable.

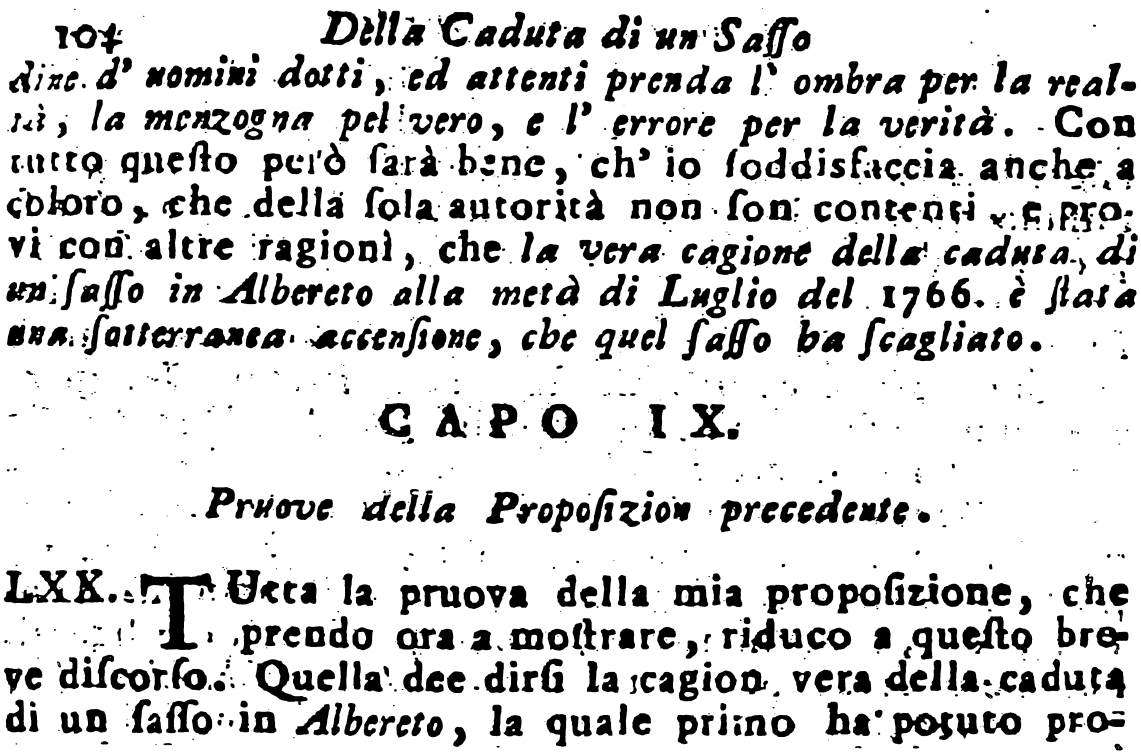
Proposition I: *The subterranean explosions had sufficient force to hurl the stone far away.*

Proposition II: *Only a subterranean explosion could have hurled a stone over Albereto.*

Proposition III. *All the reported phenomena can be explained by a falling stone hurled skyward by a subterranean explosion.*

Proposition IV. *The subterranean explosion is the actual cause not an arbitrary explanation.*

Shortly after Troili's book was printed, Monsignor Giuseppi Maria Fogliani, the Bishop of Modena, informed Troili that he



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dine d' uomini dotti, ed attenti prenda l' ombra per la realtà, la menzogna pel vero, e l' errore per la verità. Con tutto queſto però ſarà bene, ch' io ſoddisfaccia anche a coloro, che della ſola autorità non ſon contenti, e pruovi con altre ragioni, che *la vera cagione della caduta di un ſaſſo in Albereto alla metà di Luglio del 1766. è ſtata una ſotterranea accenſione, che quel ſaſſo ha ſcagliato.*

CAPO IX.

Pruove della Propoſizion precedente.

LXX. TUtta la pruova della mia propoſizione, che prendo ora a moſtrare, riduco a queſto breve diſcorſo. Quella dee dirſi la cagion vera della caduta di un ſaſſo in *Albereto*, la quale prima ha potuto pro-

FIG. 2. Troili's explanation of the fall, written in italics immediately above CAPO IX on page 104 of his book, reads: "*...the true cause of the fall of a stone in Albereto in the middle of July of 1766 is a subterranean explosion that hurled the stone skyward*". (By permission of the Houghton Library of Harvard University.)

and others disagreed with his idea of a volcanic source for the stone. The Bishop gave the following reasons:

(1) Troili did not describe the fall faithfully enough, for fear of opening arguments for other explanations

(2) By not giving the whole account, he saved himself from having to discuss other modes of origin.

(3) The event at Modena can be explained much better in other ways.

On the 11th of December, 1766, Troili responded to the Bishop in a 71-page defense, entitled, *The Explanation of the Fall of a Stone from the Air defended in an Apologetic Letter* (Fig. 3). While expressing all due respect to the Bishop, Troili defended his conclusion point by point. Then, before his *Lettera Apologetica* was sent, Troili came across a printed copy of a letter dated 1767 February 20, by the physicist, Giambattista Beccaria (1716–1781), to Benjamin Franklin (1706–1790). Beccaria had a special interest in electricity, so the main topic of his letter was his defense of Franklin's interpretation of the nature of electricity as opposed to those of his rivals. Then, in a postscript Beccaria remarked on Bishop Fogliani's ideas about the fall of the stone, criticized Troili's explanation of it, and offered his own, to wit:

> When the history of these observations is reviewed I believe that the stone was cast into the air by a thunderbolt, just as I am accustomed to explode an iron ball a distance of two or even four rods by an electric spark dispersing a drop of water...As the learned bishop adds, this confirms remarkably that the soil at Modena is everywhere full of the nearby water. Wherefore the bolt, driving through the stone, which is metallic, into the water beneath should scatter the water and hurl the stone into the air while covered in its own flash, so that it be not seen until afterwards, when it falls back down.

Beccaria took Troili to task for saying that the lightning occurred far away to the north whereas it had to have been directly overhead at "Alboretium".

In response to Beccaria's arguments, Troili added an 8-page postscript, dated 1767 March 10, to his *Lettera Apologetica* to Bishop Fogliani. In it he declared that a single lightning bolt would not suffice because as far away as Modena the gardener of His Most Serene Highness, the Sovereign Duke of Modena, told him that the explosion and the whistling frightened him so much that he feared a cannon ball from Mirandola, a nearby fortress, was about to land in the palace garden. Once again, Troili stoutly defended his conclusions and told the Bishop he felt he was being criticized unfairly in return for his sincerity and good faith. Although we do not accept his volcanic explanation today, we must acknowledge Troili's effort to use arguments that were scientific (in his time) that he believed could account for the sightings, the weather conditions, and the witnesses' reports.


IL
RAGIONAMENTO
DELLA CADUTA
DI UN SASSO
DALL' ARIA
DIFESO
IN UNA LETTERA
APOLOGETICA.

FIG. 3. The title page of Troili's 71-page letter with an 8-page postscript to Bishop Fogliano: *The Explanation of the Fall of a Stone from the Air, Defended, in a Lettera Apologetica.* (By permission of the Houghton Library of Harvard University.)

THE ALBARETO STONE IN HISTORY: TROILI AND CHLADNI

The lively debate over the fall of the stone at Albareto soon died out in the literature, and no serious interest in it was shown for more than 3 decades. Troili's book, never widely read, was not known to Ernst F. F. Chladni (1756–1827), a German physicist, when he wrote his seminal book on meteorites in 1794. With respect to Albareto, Chladni wrote (p. 37):

> At Alboreto [sic] in the summer of 1766 a stone fell from the sky and was referred to by Vassalli ((1761–1825), a professor of physics and astronomy in Turin) in a note cited in the "Lettere fisico-meteorologiche" Page 120. On the same topic, Beccaria reported the observations of Fogliani, Bishop of Modena, on the circumstances of this natural occurrence and sought to clarify it in the post script to his letter to Franklin "De electricitate vindice" of which I have things to say at the end of Section 15.

At the end of section 15, Chladni scoffed at Beccaria's lightning bolt hypothesis. Presuming that the stone was a meteorite, Chladni asked if Beccaria supposed that huge masses such as the 15 ton iron in South America (at Campo del Cielo) had been borne aloft by lightning bolts and then dropped from the sky.

Some years later, Chladni read Troili's book, which confirmed his earlier belief that the Albareto stone was a meteorite. Chladni rejected Troili's arguments for its volcanic origin and listed it as a valid fall, to which he devoted nearly a full page in his book, *Über Feuer-Meteore,* published in 1819. By that time meteorites were fully accepted by scientists and Chladni had become an avid collector and cataloger of them. He recalled that when he visited "there" (presumably Modena) he asked to see the stone but was told there was nothing left of it. Chladni, sadly concluded that the Albareto stone had been lost to science, as had so many other fallen meteorites throughout history.

But the stone was not wholly lost. In 1863, after nearly a century of neglect, interest in it was revived by Wilhelm Karl Haidinger (1795–1871), the mineralogist at the Imperial Mineral Cabinet in Vienna, who reviewed its history and wrote a modern mineralogical and chemical description of it. Haidinger explained that he had a specimen to examine because one of the scientists in Vienna, Herr R. P. Greg, had been struck with the thought that fragments of the Albareto stone might still exist in the collection at the University of Bologna. Acting on this, the Director of the Imperial Cabinet, Dr. Moritz Hörnes, contacted professors in Bologna with whom he was well acquainted and they, in turn, contacted a professor at the University Museum in Modena. Presently a sample of the Albareto stone arrived in Vienna, where the collection still includes an 80-g specimen.

Haidinger was particularly interested in Troili's report of marchesita, which was commonly lumped with other poorly defined iron sulfides under the name: magnetkies. The composition of this mineral, found in both stony and iron meteorites, had puzzled chemists for decades. As early as 1802, Jacques-Louis de Bournon (1751–1825) had separated fractions of it from four fallen stones (Siena, Wold Cottage, Benares, and Tabor) and described it as a reddish-yellow, non-magnetic iron sulfide which he called "martial pyrites". His colleague, Edward C. Howard (1774–1816) called it a "peculiar pyrite" but could not satisfy himself that he had analyzed a pure phase. For the next 60 years or so chemists tried to distinguish between species of iron sulfides, an effort that often was complicated by traces of impurities such as Ni, Co, As, Cu, or Cr. By 1855, four chemists had reported that the species in meteorites was stochiometric iron sulfide (FeS). Although disputes about its composition continued, C. F. Rammelsberg (1813–1899) in his *Handbuch der Mineralchemie* (1860, p. 905) listed FeS as a valid mineral species uniquely occurring in meteorites.

Haidinger argued that this mineral should have its own name. And inasmuch as Troili was the first person to describe grains of it in a meteorite, and the chemist, Friedrich Wöhler, had assured him that the grains were pure FeS, Haidinger (1863:289) wrote:

> I believe that with the approval of my highly respected friend (Friedrich Wöhler), who is one of the foremost investigators of the minerals of meteorites, I may be allowed now to suggest for this meteoritic mineral a specific name:
>
> *Troilite*
>
> This proposal honors the memory of the conscientious, learned, unbiased reporter on the fall of mid-July 1766 at Albareto near Modena, Domenico Troili, who with such great zeal recorded the actuality of meteorite falls a generation before Chladni's great work argued for it. His word had not prevailed and Chladni had long ago fashioned his views and achieved his success when Troili's book was already history.

Haidinger's proposed name was accepted and duly recorded for the mineral by Gustav Rose (1798–1873), the mineralogist at the Mineralogical Museum of Humboldt University in Berlin. For many years, troilite was considered by some chemists to be a variety of pyrrhotite ($Fe_{1-x}S$), an iron sulfide that, typically, is non-stochiometric. But the minerals differ in that pyrrhotite possesses a defect structure and is magnetic, and troilite, with its simple hexagonal structure, is non-magnetic. Troilite is found in virtually every meteorite but is extremely rare in terrestrial rocks, whereas the opposite is true of both pyrrhotite and of pyrite (FeS_2). The mineral we now call marcasite (also FeS_2) is a low-temperature, secondary iron sulfide found in sediments or mineralized veins on the Earth. To date, it has been found in only one or two of the meteorites that came from another planet, Mars.

In the early 1840s two fragments of Albareto, weighing ~920 and 185 g, respectively, were acquired by the University of Modena's Museum of Natural History (Chinellato, 2001). Today the largest remaining mass of Albareto, weighing 605 g and classified as an L4 chondrite, is on display in the Modena museum (Fig. 4). Fragments of Albareto totaling ~512 g currently are cataloged in more than a dozen other institutions, and some pieces reportedly are in private hands (Chinelatto, 2001:39). The weight of the original stone has been listed as 2 kg (Grady, 2000:63) and as 12 kg (Hey, 1966; Baldanza and Triscari, 1978; Chinellato, 2001). In the 1977 *Appendix to the Catalogue of Meteorites*, Hutchison, Bevan and Hall, of the British Musuem, reported that they changed the estimate of 12 to 2 kg on the advice of Dr. G. R. Levi-Donati, of the State Technical Institute in Perugia, who pointed out that there are considerably <2 kg of surviving material. However, as noted above, Troili (1766) called the stone extremely heavy (*grandissimo peso*, page 2), and he estimated that before it was smashed to pieces it would have weighed ~12 kg (*25 libbre*, page 73). We favor Troili's own estimate of 12 kg, because his

FIG. 4. The largest remaining fragment of the Albareto stone is exhibited with its historic label in the Museum of Natural History at the University of Modena. The label indicates that this specimen No. 163, an aerolite weighing 687 g that fell in mid-july, 1776, at Albareto. The weight of the specimen has since been reduced to 605 g. In this view, the stone is ~12 cm across from corner to corner. (Courtesy of Matteo Chinellato of Modena.)

phrase "*grandissimo peso*" would scarcely apply to a 2 kg stone. Furthermore, we feel that the larger size helped to account for our good fortune in having any pieces at all survive the destruction and dispersal of samples at the time of the fall.

Haidinger wrote a new mineralogical description of the stone but he did a disservice to history when he declared that Troili was first to record the actuality of meteorite falls a generation before Chladni did. While it is true that Troili clearly described a meteorite fall in 1766, he did not think of it as one nor did he suppose that it originated in space. As indicated above, Troili argued positively and consistently that the stone was hurled into the sky by a subterranean volcanic explosion. Haidinger mentions this and duly quotes Troili's statement of the "true cause" of the fall; nevertheless he applies an anachronistic judgement to the effect that inasmuch as we now know that the stone of Albareto was a meteorite from space we should credit Troili as the first author to describe one. Such a use of hindsight, known as "presentism", is anathema among historians, who take great pains to place a person's accomplishments in the context of his or her own time.

Haidinger's approach also involves an invalid *non sequitur* by implying that if we know an object is a meteorite we know it fell from space. That is true today, but by no means was it true in Troili's time and it was not yet fully accepted in Haidinger's time. The idea of an origin in space was first proposed in 1794 by Ernst Chladni after he investigated records of meteors, fireballs, and falling bodies and concluded that descriptions by witnesses, far removed from each other in time and space, had been so consistent for so many centuries that bodies falling from the sky must be authentic natural phenomena. From his knowledge of the physics of falling bodies, Chladni calculated that the velocities of meteors and of fireballs streaking down the sky are much higher than those that could be obtained by any objects originating on the Earth or in the atmosphere. Therefore, Chladni argued that small bodies originating in space either as debris left over from planet-making or from planetary collisions, enter the atmosphere at cosmic velocities, form fireballs as they decelerate due to frictional heating, and some of them land on Earth as meteorites. He then gave a brief description of every meteorite fall in the historical record that he judged to be credible. Chladni wrote later that he hesitated

to publish his book because it departed so radically from the scholarly beliefs of his time, which were based on the dictum of 1604 by Isaac Newton (1642–1727) that interplanetary space is empty of all small bodies (*e.g.*, Marvin, 1996).

Chladni began to receive the criticism he foresaw, but within 4 years he was completely vindicated by the fortuitous occurrence of four witnessed and widely publicized meteorite falls: at Siena in 1794, Wold Cottage in 1795, Portugal in 1796, and Benares, India, in 1798. By that time the fact of falling stones was beginning to be accepted, and all lingering doubts finally vanished after 1803 April 26, when a shower of nearly 3000 stones fell at L'Aigle a short distance southwest of Paris. Consequently, Chladni's assertion that meteorites fall from the sky was fully accepted shortly after the beginning of the nineteenth century, but his theory that they originate in space was not.

In 1795, Sir William Hamilton, the English Ambassador to the Court of Naples, argued that the shower that fell at Siena consisted of ash from Mt. Vesuvius that had been borne aloft for 250 miles until it consolidated into stones over that city (*e.g.*, Marvin, 1998). Ideas of a terrestrial volcanic origin for meteorites lingered on for another decade or two. Meanwhile, in 1803, a book entitled *Lithologie Atmosphérique* by Joséf Izarn (1766–1834) was published in Paris and it acquired a wide following. Izarn argued that meteorites form by the consolidation of dust and small particulates in the atmosphere, an idea based on suggestions made in 1789 by Anton-Laurent de Lavoisier (1743–1794). At that time, the main alternative to this theory of atmospheric origin was that meteorites are ejected by volcanoes on the Moon. Both of these ideas persisted until the early 1860s. By then, many astronomers and other scientists had begun to take seriously a possible origin of meteorites in space, and debates began as to whether they came from interplanetary space or interstellar space, or both (Marvin, 1996). In any case, Chladni's ideas were truly original and he was far ahead of his time.

Effects of Haidinger's arguments to bestow Chladni's laurels upon Troili are found in some modern writings on meteorites. For example, in his book *Out of the Sky* published in 1952, Harvey H. Nininger (1887–1986) complained that scholarly men of the eighteenth century were so very slow to accept the authenticity of meteorites. Nininger wrote (p. 10):

> D. Troili in 1766 published the account of the fall at Albareto, Italy, in July of that year, but his report fell upon deaf ears so far as scientists were concerned . . . Generally, Chladni has been credited with being the first to properly evaluate the arrival of meteorites from space. Actually, Troili furnished a perfectly valid account of the Albareto fall nearly thirty years earlier and furnished a mineralogical description of the material which was preserved from that fall. Chladni's contribution consisted principally in the compilation of numerous accounts which previously had failed to receive endorsement from scientific "authorities." True, he also set down detailed descriptions of specimens and critically evaluated circumstances surrounding finds and falls so as to render the proposition of increment from space convincing. But this was made possible by the large list of records previously made by other men.

Twenty years later in *Find a Falling Star* Nininger (1972) repeated much the same criticism, stating (p. 7) "*Troili correctly deduced that the Albareto stone came from space, but his conclusion fell on deaf ears so far as scientists were concerned*".

More recently, Peter Schultz, of Brown University, recalled that Chladni was challenged and discredited for his "incredulous speculation" that a mass of iron in Siberia must have had a cosmic origin. Schultz wrote (1998:10):

> According to H. H. Nininger, Chladni was not the first to be discredited for such a notion. D. Troili also carefully documented a fall in 1766 at Albareto, Italy, and he proposed a cosmic origin. Because Troili dared to propose such an origin without the benefit of other previous accounts, Nininger rightfully credits him with the pioneering breakthrough.

One more, very different version, owing nothing to either Troili, Haidinger, or Nininger, is found in the magnificent new book, *Meteorites: A Journey Through Space and Time,* by Alex Bevan and John De Laeter (2002:20):

> Troili described a 2-kg stony meteorite that fell near Albareto in the Romagna area of Italy in July 1766. Although he did not doubt that it had fallen from the sky, Troili thought it had originated in the atmosphere.

We are writing this paper in an effort to set the record straight. Admirable as Troili's work was, he did not describe a fallen stone as a meteorite, nor did he believe that the stone originated in space or in the Earth's atmosphere. All honors for his remarkably prescient insight that meteorites originate in space belong to Ernst Florenz Friedrich Chladni of Wittenberg, who published it in 1794.

Acknowledgments–We wish to thank the Houghton Library of Harvard University for kindly granting permission to reproduce passages from their copy of the book by Domenico Troili. We also thank Matteo Chinellato, of Modena, for making available a picture of the Albareto stone and giving us permission to reproduce it, and two referees, Alex Bevan and Alfred Kracher, who made some very helpful suggestions for improving the manuscript.

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