Meteorites and impacts: research, cataloguing and geoethics

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Abstract

Meteorites are basically fragments from asteroids, moons and planets which travel trough space and crash on earth surface or other planetary body. Meteorites and their impact events are two topics of research which are scientifically linked. Spain does not have a strong scientific tradition of the study of meteorites, unlike many other European countries. This contribution provides a synthetic overview about three crucial aspects related to this subject: research, cataloging and geoethics. At present, there are more than 20,000 meteorite falls, many of them collected after 1969. The Meteoritical Bulletin comprises 39 meteoritic records for Spain. The necessity of considering appropriate protocols, scientific integrity issues and a code of good practice regarding the study of the abiotic world, also including meteorites, is emphasized.

Resumen

Los meteoritos son, básicamente, fragmentos procedentes de los asteroides, la Luna y Marte que chocan contra la superficie de la Tierra o de otro cuerpo planetario. Su estudio está ligado científicamente a la investigación de sus eventos de impacto. España no cuenta con una fuerte tradición científica sobre estos temas, al menos con el mismo nivel de desarrollo que otros países europeos. En esta contribución se realiza una revisión sintética de tres aspectos cruciales relacionados con los meteoritos: su investigación, catalogación y geoética. Hasta el momento se han reconocido más de 20.000 caídas meteoríticas, muchas de ellos desde 1969. El Meteoritical Bulletin indica que existen 39 registros meteoríticos correspondientes a España. Finalmente se enfatiza la importancia de considerar apropiados protocolos, aspectos de integridad científica y códigos de buenas prácticas, con respecto al estudio del “mundo abiótico”, incluyendo también a los meteoritos.

Key-words: : *meteorites, review, reasearch, cataloging, geoconservation, geoethics*

1. Introduction

The Earth is in a continuous interaction with outer space, and cosmic events related to comets, bolides, and meteorite falls have accompanied human beings since the emergence of humankind. Meteorites are unique specimens which provide essential information about the origin of the Earth, and which could also be involved in the origin of life, providing water and other inorganic and organic compounds. There is a great thematic diversity regarding the research of meteorites. Meteorites and their impact events are two topics of research which are scientifically linked; nevertheless, studies concerning impact craters/events started relatively recently in history of science. It is extremely important to consider the study of meteorites from a global perspective, taking into account a geoethical approach and the significance of their appropriate geoconservation.

2. Research

Despite some authors discuss the exact paternity about who, when and what set off the first scientific proposal about the extraterrestrial origin of meteorites, there is a general agreement about the pioneer role of E.F. Chladni *(Fig.1)*, as the true father of such idea. However, how was

Fig. 1. E.F. Chladni (Germany, 1756–1827) is considered one of the founders (if not the real father) of modern meteorite research. Photo: Courtesy of meteoris.de.

this German physicist going to know, when he proposed in 1794 the extraterrestrial origin of the meteorites *(Marvin, 2007)*, the extraordinary historical and scientific implications of his famous work "On the Origin of the Pallas Iron and Others Similar to it, and on Some Associated Natural Phenomena"? In this study, Chladni compiled all available data about meteoritic finds and falls and concluded that they should have their origin in outer space. However, despite the scientific relevance of the epoch as a time of exciting discoveries, the response of the scientific community, with the exception of some experts, such as Olbers in Germany and Howard in UK, was to ridicule his ideas stating that the fall of meteorites from the sky was "impossible" *(Martínez-Frías and Barrera 2000, Martínez-Frías et al. 2006)*. As it is very well explained in http://fireballs-meteorites.blogspot.com.es, The idea that stones can fall out of the sky was mockingly denounced by the Académie Française des Sciences in Paris as an unscientific absurdity. Antoine Lavoisier, for example, told his fellow Academicians, "Stones cannot fall from the sky, because there are no stones in the sky!" Embarrassed museums all over Europe (e.g. Vienna), wishing to be seen to be part of this open-minded "Age of Reason", hurriedly threw out their exquisite meteorite collections with the rubbish as humiliating anachronisms from a superstitious past. This ultra-orthodox behaviour delayed the progress of meteoritics. People who even witnessed meteorite falls were even denounced as superstitious ignorant peasants. Almost ten years later, on the night of the 26th of April 1803, perceptions started to change. On that night the people of L'Aigle (France) were astonished by the thunderous noise of more than 2000 rocks falling from the sky. This irrefutable display of meteorites also woke up the Académie who was obliged to take notice (see http://fireballs-meteorites.blogspot.com.es). They appointed a commission, coordinated by Jean-Baptiste Biot, to investigate the event, the result of which was at last a reluctant recognition that stones could in fact fall from the sky. Museums, freed from the stigma of non-conformity, started building meteorite collections once again. In accordance with *Grady (2000)*, there have been around 1,000 observations of meteorite falls, although this just represents a small fraction of the objects which reach the earth surface (most of them falling in oceans and unpopulated areas). On the contrary, there are more than 20,000 meteorite falls, many of them collected after 1969, when it was discovered that they can be found in some specific areas (e.g. Sahara and Atacama Deserts and Antarctica). However, it is estimated that only a 1% of the total material from space is recovered. Today, 219 years after the Chladni's proposal, a bibliometric search for the term "meteorite" in the prestigious Web of Knowledge yields, since June 1881, more than 16,000 records (16,092), 14,891 of them included in the Web of Science.

Meteorites are basically fragments from asteroids, moons and planets which travel trough space and crash on earth surface or other planetary body (e.g Mars, where some meteorites have already been found by the rovers - http://geology.com/articles/mars-meteorites). Nevertheless, given the terminological confusion concerning this subject, it appears appropriate to offer some simple and synthetic definitions about the concepts *(NASA, 2013)* of meteoroid, meteor, fireball, bolide and meteorite. Meteoroid is a small particle from a comet or asteroid orbiting the Sun. Meteor is the light phenomena which results when a meteoroid enters the Earth's atmosphere and vaporizes; a shooting star. According to the American Meteor Society, 'fireball' is a term for a very bright meteor, generally brighter than magnitu-

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de _3 or _4, which is about the same magnitude as the planet Venus viewed in the morning or evening sky. If the fireball explodes in a bright terminal flash, which typically extinguishes with visible fragmentation, it is then known as a 'bolide', from the Greek word for a throwing spear. None of them must be confused with "megacryometeors" (name large atmospheric ice conglomerations which, despite sharing many textural, hydrochemical and isotopic features detected in large hailstones, are formed under unusual atmospheric conditions which clearly differ from those of the cumulonimbus clouds scenario - i.e. clear-sky conditions, *Martinez-Frias & Travis (2002), Martínez-Frías et al. (2005), Orellana et al. (2008))*. Meteorite is a meteoroid that survives its passage through the Earth's atmosphere and lands upon the Earth's surface. A simple, but extremely important, distinction of meteorites is between "falls" and "finds". Meteorite falls are collected after their fall from space was observed by people or automated devices. All other meteorites are called "finds". Some basic information about meteorites can be found, in *Wasson (1985), Kerridge & Matthews (1988), McSween (1999), Bevan & De Laeter (2002), Norton (2002), Beech (2006), Martínez-Frías et al. (2006), Hutchison (2007)*, among others.

In order to describe the typology of meteorites we will focus, due to their extraordinary abundance and pristine nature, on asteroidal meteorites (> 99,9%), excluding those coming from the Moon and Mars *(Korotev (2013), Baalke (2013)*. Recently, it has been proposed that meteorite NWA7325 *(Fig.2)*, which was found in Morocco in 2012, could be the first known meteorite from Mercury *(Irving et al. 2013)*. There exist three main categories of meteorites *(Weisberg et al. 2006)* : Iron meteorites (almost 100% metal – Fe/Ni), Stony-iron meteorites (nearly 50% metal and 50% silicates), and Stony meteorites (mainly silicates). The majority of meteorite falls are stony meteorites: Chondrites and Achondrites. Chondrites have never extensively melted and have compositions similar to the sun and the solar system as a whole. Achondrites have melted and are similar to igneous rocks on Earth. These include rocks from Mars and the moon as well as from melted asteroids. Achondrites have compositions different from the sun as they have been changed by melting and crystallisation. Both chondrites and achondrites are split into many sub-groups based on their compositions, minerals and structures. The most abundant constituents of chondrites are chondrules, which are tiny spherules of millimetre size containing olivine, pyroxene, metal, sulfide and glass *Hewins et al., 1996, Boss & Durisen, 2005, Sears, 2011)*. Chondrites have been compared with sedimentary rocks built from pre-existing nebular materials, with different origins, formed by accretion in the asteroids. Besides chondrules, chondrites also comprise CAIs (Ca-Al inclusions), normally ameboid aggregates of olivine, interstellar particles, and opaque particles, embedded in a fine grain matrix. It is assumed that CAIs are among the first solids condensed from the cooling protoplanetary disk (reflecting the heterogeneity of the pristine solar nebulae), dated by Rb-Sr and Pb-Pb in around 4,560 Ma in the Allende meteorite. Although their shape is variable, most CAIs display a concdntric structure formed by layers of different refractory minerals (e.g. corundum, hibonite, perowskite, anortite, melilite and spinel). There are four main classes of chondrites, subdivided into 15 groups on the basis of their mineralogy, bulk chemical composition, and oxygen isotope compositions: enstatite chondrites (E: EH and EL), carbonaceous chondrites (C: CI, CM, CO, CV, CR, CK, CH and CB), ordinary chondrites (O: H, L and LL) and Rumuruti chondrites (R). This last one was recently defined, after the analyses of five specimens displaying the same features (this is the minimum number to

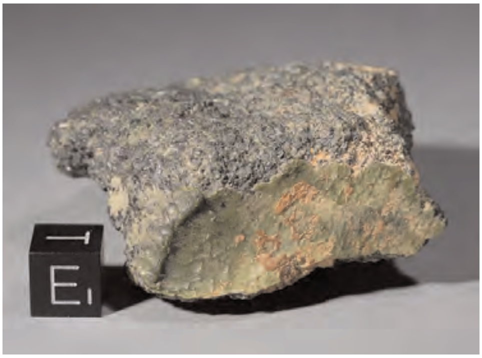

Fig. 2. NWA 7325 is the name for a meteorite fall that was spotted in southern Morocco in 2012, comprising 35 fragments totaling about 345 grams. In a recent study, it has been suggested (Irving et al. 2013) that it could be the first known meteorite from Mercury. Photo: Courtesy of Stefan Ralew/SR Meteorite.

define a new class). An additional class (Kakangari chondrites) is not still accepted and recognized by all authors. Achondrites are stony meteorites without chondrules. The term comprises different type of specimens: rare (intensely recrystallized and partially molten) chondrites, other more numerous igneous rocks (and mechanical mixtures –breccias- of igneous fragments derived therefrom), among others. These meteorites are diverse objects, which comprise from very primitive chondrites to even monomineral rocks, which are similar to terrestrial dunites or pyroxenites (texturally resembling basalts). Achondrites include: a) the so-called primitive achondrites: acapulcoites, winonaites and lodranites; b) the SNC meteorites (although it is an independent group - Shergottites, Nakhlites, Chassignites and ALH84001). It is assumed that they originate from Mars; c) aubrites, ureilites, angrites and HED chondrites (howardites, eucrites and diogenites), and d) lunaites, lunar meteorites (also as an independent group). Stony-iron meteorites divide into pallasites and mesosiderites. Pallasites are a rare type of meteorite. They consist of cm-sized olivine crystals in an Fe-Ni matrix. Coarser metal areas develop Widmanstätten patterns upon etching. Minor constituents are schreibersite, troilite, chromite, pyroxenes, and phosphates (whitlockite, stanfieldite, farringtonite, and merrillite). Mesosiderites can be defined as mechanical mixtures, with different degree of recrystallization of silicates and metal. Finally, Iron meteorites normally consist of approximately 90 to 95% iron, with the remainder comprised of nickel and trace amounts of heavy metals including iridium, gallium and sometimes gold. The vast bulk of these meteorites consists of the Fe,Ni-alloys kamacite and taenite.Minor minerals, when occurring, often form rounded nodules of troilite or graphite, surrounded by schreibersite and cohenite. Iron meteorites are classified using two different systems: chemical composition and structure. There are thirteen chemical groups for irons, of which IAB is the most common. Irons that do not fit into an established class are described at Ungrouped (UNGR). Structural classes are octahedrites, hexahedrites and ataxites.

The significance of defining typological criteria, establishing classifications, and the mineralogical and geochemical characterizations were, without doubt, prioritary steps in the investigation of meteorites, in order to determine and understand their wide compositional spectrum. However, meteorites were also extremely important for helping to know the age of the Earth (and the Solar System). Many other specific studies regarding chondrules, CAIs, isotopic ratios, etc. were also crucial in the history of meteoritics. Much more recently, some works, directly or indirectly related to panspermia and the spectacular rise of Astrobiology, have also opened new fields of research for the identification of geo and biomarkers in meteorites, from different approaches. In this sense, it is curious to note that the first WoS' record about meteorites is a publication entitled: "Fossil organisms in meteorites" *(Rachel, 1881)*. A more in-depth review of the subjects, and other aspects related to meteorites, allow a more detailed characterization concerning the whole set of references. Thus, taking into account the WoK database' cathegories, the five most relevant are: "Geochemistry Geophysics" (50,67%), "Astronomy Astrophysics" (16,99%), "Multidisciplinary Sciences" (10,54%), "Geosciences Multidisciplinary" (9,39%) y "Mineralogy" (3,56%). Likewise, the five most relevant journals are: "Meteoritics & Planetary Science" (17,04%), "Geochimica et Cosmochimica Acta" (11,64%), "Meteoritics" (7,05%), "Earth and Planetary Science Letters" (4,45%) y "Nature" (3,53%), being the USA the country which covers, with 7,010 references, nearly 50% (47,07%) of all records. Spain occupies the 16th position with 195 records about meteorites (around 1.31% of the total number of publications). Most of them are articles (68,33%) published in scientific journals (10,175 articles), and the main institutions which are responsible for this productivity are: NASA, University of California, Max Planck Society, Washington University and University of Chicago.

As previously defined, meteorites and their impact events are two topics of research which are scientifically linked. The Earth's magnetic field and our atmosphere form a shield protecting the planet's surface from energetic, charged particles coming from the Sun and other places as well as from the entrance of millions of meteoroids and micrometeoroids. Every day, the Earth is bombarded with more than 100 tons of dust and sand-size particles. Many of the incoming particles are so small that they are destroyed in the Earth's atmosphere before they reach the ground. Approximately, 500 meteorites larger than 0,5 kg fall every year, although only 4 are observed (in populated areas). The vast majority fall on the oceans and seas. Nevertheless, the study of the geological record of the Earth, the Moon, and the rest of planets of the Solar System, evidences the existence of numerous impact craters. In our planet, the oldest record of impact events corresponds to the Lower Archean layers of spherules which have been identified in the South African "Barberton Greenston Belt" *(Lowe et al. 2003)*. At present, we know that meteorite impacts have accompanied the geobiological evolution of the Earth and that, to date in accordance with the The Earth Impact Database (EID - http://www.passc.net/EarthImpactDatabase/) there are 184 confirmed impact structures *(Fig.3)*, with diameters ranging from meters to hundred kilometers (*Napies & Clube, 1979, Melosh, 1989, Chapman & Morrison, 1994, Osinski & Pierazzo, 2012, Koeberl & reynold, 2013)*.

It has been estimated that once every few hundred years, on average, the Earth is hit by an object about 70 meters in diameter; every 10,000 years by an object of around 200 m, and of around 2 km in diameter each 106 years. A global catastrophe, similar to that of the K-T bounday (Alvarez et al. 1980), produced by an object of around 10 km, would occur each 100 million years. This impact event was probably the cause of the giant impact structure of Chicxulub (Gulf of Mexico) *(Hildebrand et al. 1991, Hodges, 1994),* which was responsible, at least in part, for for the extinction of dinosaurs and many other species about 65 million years ago. From a historical –and also scientific– point of view it is important to highlight the famous Barringer Meteor Crater (previously known as Coon Mountain o Coon Butte), whose impactogenic origin was firstly suggested, in 1903, by the mining engineer Daniel Barringer and later confirmed, after the studies of Fairchild (1907), by the astrogeologist Eugene M. Shoemaker *(Shoemaker and Kieffer, 1979)*. Basically, the results obtained by Shoemaker are considered the first definitive evidence of an extraterrestrial impact on our planet. In Spain, several authors propose the existence of impact craters (e.g. Azuara structure, Zaragoza) *(Ernstson et al. 1985, Ernston et al. 2001)*. Nevertheless, in accordance with our studies *(Cortes et al. 2002, Díaz-Martínez et al.*

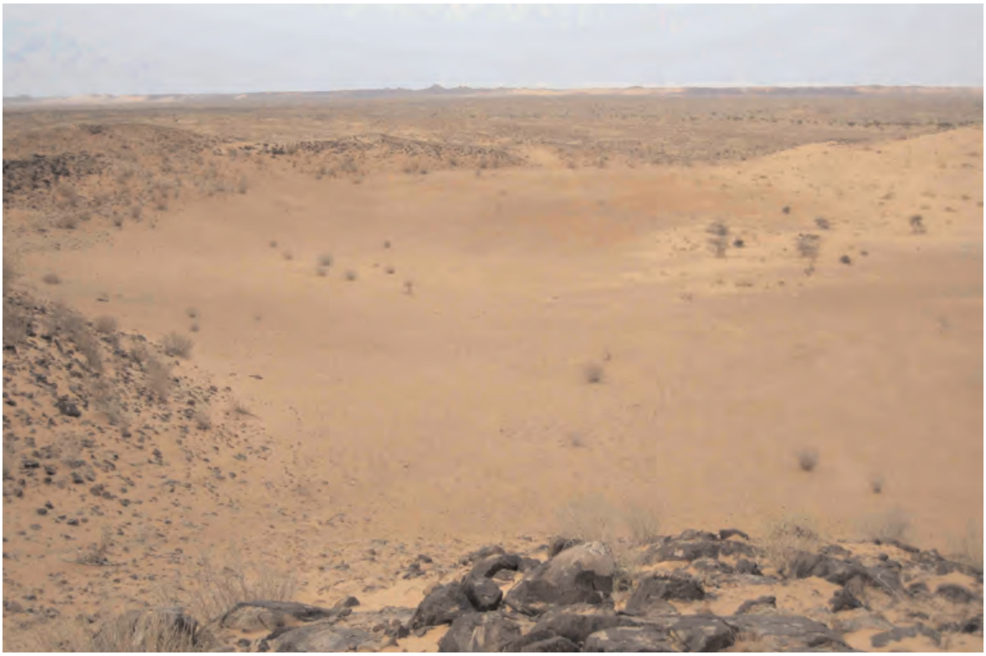

Fig. 3. General view of the impact crater of Aouelloul (Mauritania). Ø: approx. 390 m. (Martínez-Frías et al. 2008).

2002), and with the international impact structure database of the University of New Brunswick (http://www.passc.net/EarthImpactDatabase/), there are not evidence enough, at least until now, to assign an extraterrestrial origin. A detailed review in the WoS database of the terms "Meteorite" and "Impact" yields more than 2,000 records (2,258), in which the five main cathegories are: "Geochemistry Geophysics" (48,85%), "Astronomy Astrophysics" (19,04%), "Geosciences Multidisciplinary" (14,30%), "Geology" (4,65%), y "Mineralogy" (2,97%). The three most important journals (comprising the majority of articles) are: "Meteoritics Planetary Science" (17,49%), "Geochimica et Cosmochimica Acta" (9,88%) y "Earth Planetary Science Letters" (5,89%), and the USA is the country which covers more than 50% (50,17%) of all publications, principally carried out by NASA, University of California y Johnson Space Flight Center. Spain appears in the position 14, with the 1,77% of all publications.

3. Cataloging

In accordance with the Meteoritical Society http://meteoriticalsociety.org/?page_id=58, the Meteoritical Bulletin (MB) Database "*is a searchable electronic resource that contains information about all known meteorites, and mirrors the information on new meteorites published in the Meteoritical Bulletin. The primary function of the Meteoritical Bulletin Database is to provide authoritative information about meteorite names. The correct spelling, complete with punctuation and diacritical marks, of all known meteorites recognized by the Meteoritical Society maybe found in this compilation. The catalogs that are indexed contain detailed information about the meteorites, including narratives of the discovery, mineralogy, petrology, specimen locations, chemical and isotopic composition, and references to the literature"*. All specimens included in the MB are considered as accepted by the Nomenclature Committee of the Meteoritical Society. In a certain way, meteorite cataloguing is also a cultural indicator, as it requires a scientific component of the country which involves, collecting, studying, and classifying the meteorites as well as to know and follow the necessary procedure for their incorporation into the MB. Obviously, this analysis is not applicable when we refer to comparisons between large and small countries or to those which special and privilege areas for finding meteorites (e.g. deserts like Sahara or Atacama). A review in the MB of the meteorites which are recorded, in accordance with their respective countries, indicate, for instance, 39 meteoritic record for Spain, 44 for UK, 60 for Italy, 72 for Germany, 84 for France and 1,923 for the USA.

As indicated in *Martinez-Frías & Madero (2004)* and *Martínez-Frías & Lunar (2008)*, unfortunately, Spain does not have a strong scientific tradition of the study of meteorites, unlike many other European countries. This is probably the main reason why none of the Spanish meteorite collections appears in the noteworthy compilation carried out by *McCall et al. (2005)*, as a special publication of the world's oldest national scientific and professional society for earth scientists (The Geological Society of London). Thus, whereas the meteorites from the Natural History Museum of Vienna, the Museum für Naturkunde, Berlin, the Natural History Museum, London, the National Museum of Natural History in Paris, and the Vatican are well represented in such publication and named as *"key meteorite collections"* by *McCall et al. (2005)*, there is a conspicuous absence of Spanish collections. However, the limited Spanish scientific background in meteoritics – which has, sadly, run in parallel to that of science as a whole in the country – does not imply that remarkable meteorite collections do not exist in Spain's museums; on the contrary, some of them host extraordinary meteorite specimens with added historical value – for example, Museo Nacional de Ciencias Naturales (MNCN). The meteorite collection of the National Museum of Natural Science (MNCN) reflects well the historical and scientific evolution and situation of the studies about meteorites in the country. The significant number and typological variety of the MNCN's specimens, the set of research studies and, above all, its extraordinary historical value, make this collection the most important of Spain *(Martinez-Frías et al 1989)*. The oldest meteoritcal fall represented in the Museum goes back to 17 November 1773 in Sena, Huesca (classified as H4 chondrite). In accordance with the last updating of the catalogue in the Meteoritical Bulletin *(Muñoz-Espadas et al.*

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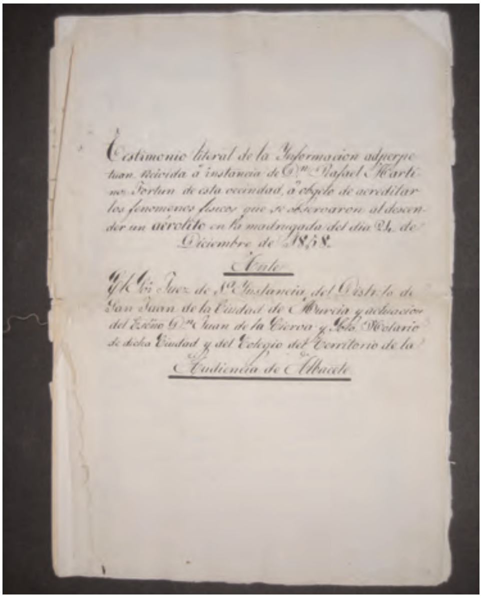
2002), the collection comprises 88 stony meteorites, 56 iron meteorites and 13 stony irons. The first initiative to systematize the meteorite collection of the MNCN was conducted by the Marquis of Socorro, during the second half of the XIX century (1866-1882). Then the collection included 68 specimens corresponding to 64 meteorites. In 1916, 99 specimens from 94 meteorites were listed and, by 1923, the collection contained 168 specimens *(Fernandez Navarro 1923)*. This total increased in the following decades thanks to private donations. A later inventory of the collection published by *King et al. (1986)* numbered 217 specimens from more than 155 different meteorites. Three years later an overview focusing on Spanish meteorites was carried out by *Martínez-Frías et al. (1989)*. In *Barreiro (1992)* many other details are described regarding the circumstances surrounding many falls. The first complete scientific studies of the meteorites go back to the beginning of the XIX century and the middle of the XX century. Much more recently, the petrologic and geochemical features of some meteorites (Oviedo, Cabezo de Mayo, Sevilla, Gerona, Cañellas, Madrid, Nulles, Los Martínez, Guareña, Olmedilla de Alarcón, Reliegos and Molina de Segura) of the collection were characterized by different authors *(Sanz & Wasserburg, 1969, Sanz et al. 1970, Williams et al. 1985, Keil et al. 1986, Casanova et al. 1990, McCoy et al. 1990)*. Other studies focused particularly on the circumstances surrounding some historical falls *(Martin-Escorza 1987, Alcala and Martin Escorza 1996, 2000, Muñoz-Sanz, 1997, Ordaz et al. 1999)* and the study of selected ordinary chondrites from the Museum's collection as part of a PhD thesis *(Muñoz-Espadas 2003)*. Finally, a specific analysis by using Raman spectroscopy was carried out on some chondrites of the collection *(Rull et al. 2010)*.

From a historical (and scientific) point of view, it is important to stress that, since the impressive meteorite fall of Reliegos in 1947, 50 years passed before a new Spanish meteorite was catalogued in the Meteoritical Bulletin: the Valencia meteorite. In 1994 a supposed meteorite struck a car in the town of Getafe (South Madrid). Studies indicate that, although the circumstances surrounding the fall are well documented, the petrologic and geochemical characteristics of the material (a larnite-rich ultra-refractory rock) do not match any of the previously classified meteorites or clearly terrestrial rocks *(Martinez-Frias, 1998, Martínez-Frías et al. 1999, Martínez-Frías et al. 2004a,b)*. Thus, we included this in the catalogue as a pseudometeorite *(Muñoz-Espadas et al. 2002)* and a special statement was made about it by the Nomenclature Committee of the Meteoritical Society (http://tin.er.usgs.gov/meteor) citing our work. Further information about the Getafe pseudometeorite – probably a piece of electric arc furnace slag – can be found at http://tierra.rediris.es/merge/ getafe.html). Our results were also ratified by *Garcia-Guinea et al. (2005)*. A recent review of the meteorite collection *(Garcia-Guinea et al. 2006)* includes the new acquisitions of Spanish meteorites (Villalbeto de la Peña and Puerto Lápice) which correspond to finds that have been related to the bolides of 4 January 2004 and 10 May 2007 (see, among others, *Martinez-Frias & Madero, 2004, Llorca et al. 2005, Madiedo et al. 2008, Trigo et al. 2009*). It is important to note that, whereas the bolides were widely observed in different parts of the Iberian Peninsula, *"there were no direct witnesses of the meteorite falls, and no pieces were collected coinciding simultaneously with the observation of the bolides"*). The first fragment of Villalbeto de la Peña was found seven days after the bolide event and the first fragment of Puerto Lápice after 24 days. Other fragments were found subsequently, which were assigned to these bolides (see http://tin.er.usgs.gov/meteor/).

The Natural Science Museum of Tenerife (Canary Islands) houses another significant collection of meteorites, whose research has been recently initiated *(Hernández et al. 2010)* and that would require higher institutional and scientific support. It is important to stress that several meteorites from this Collection were already included by our research team in the Meteoritical Bulletin.

Given the context in which the present contribution is set, it is appropriate to highlight that Murcia has great historical and scientific relevance in relation with the study of meteorites and their impact events: a) Molina de Segura (Murcia) is the site of the largest meteorite to land in Spain *(Martinez-Frias y Lunar, 2008) (Fig.4)*; b) the Barranco del Gredero section (Caravaca, Murcia) is one of the most complete,


Testimonio literal de la Información ad perpetuam Recibida á instancia de Dn. Rafael Martinez Fortun de esta vecindad, á objeto de acreditar los fenómenos físicos que se observaron al descender un aerolito en la madrugada del día 24 de Diciembre de 1858.

Ante

El Sr. Juez de 1a Instancia del Distrito de San Juan de la Ciudad de Murcia y actuación del Escmo. Dn. Juan de la Cierva y Soto Notario de dicha Ciudad y del Colegio del Territorio de la Audiencia de Albacete

Fig. 4. First page of the historical document 0258/004, which includes a description of the fall of the Molina de Segura meteorite (MNCN). The document was first presented by Martínez-Frías & Lunar (2008). It is important to note that an error in the Museum Archive number was detected, thanks to the help of the Museum's staff. This error is present in all previous historical articles: the archive number is not 169 but 258/004 (http://aleph.csic.es).

expanded and well exposed Cretaceous/Tertiary (K/T) boundary sections in the world, *(Fig.5)* recently known as Cretaceous-Paleogene (K-Pg) (see, among others, *Martínez-Ruiz et al. 1992, Duran et al. 1997, Arana Castillo et al. 1999, Molina, 2004, Del Ramo Jiménez y Guillén Mondejar, 2004, Smit, 2004)*, and c) two more Spanish meteorite fall events are known to have occurred in Murcia (Cabezo de Mayo (fall) and Los Martínez (find), although it has been sugeested that there could correspond to the same event *(Alcala & Martín Escorza, 2000)*). In broad terms, scientific publications related to the concrete cataloguing procedure of meteorites are scarce. In accordance with the WoS database, crossing the terms "Meteorite" and "Catalog" yields only 40 references. Specifically concerning Spain, 195 publications about meteorites (159 articles) are recorded in the database, corresponding to: CSIC (45.13%), Instituto Astrofísica de Canarias (13.3%) and Universidad Politécnica de Cataluña (12.82%).

4. Geoethics

The connection between ethical aspects and Nature (and the Universe) goes back to the first philosophers and naturalists of recorded history, and specific examples and names linking ethics and geology can be found in the beginning of the development of this science practically in all countries. However, Geoethics, as a new and modern discipline, was born in 1991 in Pfiíbram (Czech Republic) at the junction of Ethics and Geology *(Nemec, 1992)*, in a similar

Fig. 5. K/Pg layer (Caravaca de la Cruz, Murcia). Note its red-yellow colour: Courtesy of Prof. Eustoquio Molina.

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scientific/disciplinary fusion that Geochemistry, Geophysics or Geobiology, in which *"The Whole Is More Than the Sum of Its Parts"*. Numerous contributions on Geoethics were presented in all International Geological Congresses (Japan, China, Brazil, Italy, Norway, Australia), as well as in other specific workshops. The international institutionalization of Geoethics was established in 2004, by forming a working group for Geoethics with the backing of the Association of Geoscientists for International Development (AGID). The first works that propose the significance of geoethics in connection with the study of meteorite and planetary sciences (including astrobiology) started in 2008 *(Martinez-Frias, 2008)* suggesting a definition which also involves such issues. After the publication in the Spanish Network of Earth Sciences (Tierra) of said definition, a specific international website (http://tierra.rediris.es/Geoethics_Planetary_Protection) devoted to Geoethics was founded in 2009, in the context of the working activities of the AGID Spanish Chapter. This website was also used by other geoethics' groups (e.g. Czech Republic, Russia and Italy) to disseminate their information and news. First international publications, specifically linked to this thematic framework, are presented (*Martínez-Frías et al. 2009a,b, Martínez-Frías et al. 2010, 2011).*

It is important to highlight that, since 2010, Geoethics has been considered a fundamental subject in the context of the activities of the IUGS Commission on Geoscience Education, Training and Technology Transfer. The "International Declaration of Geoethics" was promulgated in Pribram in 2011. The first world monograph about Geoethics was published in Russia in July 2012 *(Nikitina, 2012)*. This same year, a special volume regarding geoethics and culture was published in Italy *(Peppoloni & Di Capua, 2012)*. In August 2012, in Brisbane (Australia), the AGID working group for Geoethics adopted by unanimity to establish a new *"International Association for Geoethics (IAGETH)". In accordance with the IAGETH, "Geoethics is an interdisciplinary field, which involves Earth and Planetary Sciences as well as applied ethics, regarding the study of the abiotic world (geoeducation, natural hazards, geo-mining, engineering geology, communication, geoconservation, etc). These interactions linking scientific, societal and cultural aspects, consider our planet as a system and as a model. In addition, the necessity of considering appropriate protocols, scientific integrity issues and a code of good practice –regarding the study of the abiotic world– is covered by this discipline. Planetary geology and astrobiology also require a geoethical approach."*

The following aspects are much more connected with the "abiotic world", geoethics and meteorites:

A) Regarding meteorite collectors or suppliers: geoethical issues are more related with lack of knowledge and clear illegalities.

1.- illegal trafficking of meteorites.
2.- intention of hustling and fraudulent manoeuvres, regarding authenticity and/or the source area of the "find".
3.- spurious interests to artificially increase the chrematistic value of the meteorite specimens to call the attention of museums or scientific institutions by the false or deceitful indication that "they witnessed a fall event" related to a bolide (e.g. to buy a meteorite and alleging that it is a find or fall related with a bolide previously observed).

B) Regarding geoscientists and host institutions: geoethical issues are more related with mistakes, bad scientific practice or even ethical misconduct.

1.- to give credibility, without unequivocal verification, from scientists, museistic and scientific institutions, to questionable sources of meteorite specimens (mainly in the sense of finds vs. falls) or about any other previously defined aspects.
2.- erroneous or intentional confusion between the concepts of meteorite "falls" and "finds" and the terms "bolides" and "meteorites", provoking misunderstanding to favour a higher significance or notoriety of the scientists.
3.- geoethical issues related with the correct study (scientific integrity) and preservation (geological heritage) of unique geological structures (craters) and other features originated by meteorite impacts.

Other geoethical issues are linked to the abiotic nature of the planetary bodies (asteroids, moons and planets) for their own genetic and compositional geodiversity. Thus, meteorites, as previously defined, are unique samples "per se" which:

1) yield clues about the Earth and Solar System formation;
2) played a major role in the geo/bio co-evolution of our planet (large impacts), and
3) which could also be potentially involved in the origin of life, as carriers of water, carbon and other astrobiologically significant compounds. Hence, their appropriate regulation and geoconservation is crucial.

Although legal regulations depend on the different countries and regions *(Schmitt, 2002)* there are some fundamental recommendations by UNESCO (in a historical statement in 1965, coordinated by the working group of the IUGS and IAU) indicating "the need to ensure that these objects are properly conserved for scientific study on earth"... and "the disirability of adopting legislation to ensure that meteorites are conserved and used in the public interest and in that of mankind as a whole". At present in Spain, meteorites are considered part of our geological heritage *(Law42/2007 of 13 December 2007 of Natural Heritage and Biodiversity).*

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