

Review

Stones from Space, Records on Earth: Cataloging Meteorite Collections in Italian Museums with the BN-PL National Standard: State of the Art and Future Perspectives

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Abstract

The study of astromaterials, including meteorites, provides essential insights into the origin and evolution of the Solar System. Their scientific value relies not only on analytical investigations but also on rigorous documentation and long-term preservation. In this context, standardized cataloging systems are not merely administrative acts but fundamental tools for ensuring data accessibility, safeguarding collection integrity, and facilitating knowledge dissemination within the planetary science community. Importantly, most meteorites are preserved in museum collections, making these institutions central to their conservation and study. This contribution examines the BN-PL (Beni Naturalistici–Planetologia) Italian national cataloging standard, developed by the Central Institute for Cataloging and Documentation (ICCD) under the Ministry of Culture. Specifically designed for meteorite museum collections, BNPL forms part of a legally recognized, interoperable, and open-access system. The standard comprises over 21 thematic sections, covering classification, sample availability, provenance, acquisition, analytical data, conservation policies, exhibition records, and bibliography. Each entry is complemented by high-resolution images and multimedia documentation, supporting both research and public engagement. This work outlines the state of cataloging Italian meteorite museum collections using BNPL, highlighting its strengths and limitations, while also considering the potential development of the standard for cataloging astromaterials within the national heritage framework.

Keywords: BNPL; cataloging; meteorite; museum collection; ICCD



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1. Introduction

The existing literature on museum collection management emphasizes that the systematic documentation of collected objects is as critical as their proper conservation and effective valorization. A detailed examination of natural history museums' cataloging practices over the centuries falls outside the scope of this work; however, it is worth noting the definition of cataloging in the context of mineralogical collecting proposed by Hearsh et al. [1]. Citing Turner [2], the authors describe cataloging as the process through which a raw mineral is transformed into a specimen, to which formative and world-building meanings are assigned. This perspective underscores that cataloging is not merely a procedural or administrative task, but a curatorial and epistemic act that imbues specimens with interpretative and scientific significance, situating them within broader frameworks

of knowledge, research, and cultural heritage. During the cataloging process, specimens disclose their “biographies” [3], encompassing details of their provenience, the history of ownership, physical characteristics, and their placement within established scientific classification systems. The information generated in this process is not only transmitted to the relevant scientific community but also disseminated to the wider public through exhibitions and educational initiatives (e.g., [4]). In this way, cataloging contributes simultaneously to the advancement of specialized research and to the promotion of cultural and scientific literacy. Furthermore, by ensuring systematic preservation and accessibility, cataloging guarantees that this body of knowledge will remain available to future generations of scientists, scholars, and interested members of the general public, thereby reinforcing both the scientific and societal value of natural history museum collections.

However, this process is frequently influenced by the subjectivity of the cataloger, who determines which categories of data are documented and how they are represented. In many cases, information is recorded according to in-house registration models, which are often inconsistent across institutions and limited to local databases. Such practices, while functional at an institutional level, hinder interoperability, comparability, and data accessibility [5]. The reliance on individualized approaches may also lead to the omission of relevant contextual information or to discrepancies in terminology, ultimately reducing the scientific utility of the records. Moreover, as emphasized by Rinaldo et al. [6], a substantial portion of primary cataloging resources remains in handwritten form, considerably limiting their effective use and reuse. Documents such as ancient museum catalogs and inventories are often difficult to interpret, and the lack of machine-readable formats renders their integration into digital systems particularly challenging. These constraints prevent both the accessibility and interoperability of the data, reducing its potential for large-scale analysis, long-term preservation, and broader dissemination within the scientific community.

The absence of standardized and widely shared cataloging practices has resulted in the study of these primary sources being approached selectively within the framework of geoscientific collections. For example, mineralogical cataloging has been examined from multiple perspectives, including the history of scientific collecting (e.g., [7]), the role of mineral collections as indicators of cultural, social, and political significance [8], and within the broader framework of geological power [9], encompassing colonial and imperial contexts [1,10].

By contrast, other categories of geoscientific museum collections, such as meteorite collections, have received comparatively limited attention in terms of cataloging practices. In most cases, scholarly efforts have concentrated primarily on their scientific classification and analytical investigation (e.g., [11,12]). Therefore, the study of museum meteorite collections has often been restricted to the publication of inventories, usually in journals addressed to the planetary sciences community (e.g., [13]). While these approaches are of unquestionable scientific relevance, they remain insufficient from the perspective of museum documentation and heritage management, particularly given that most known meteorites are preserved in museum contexts (e.g., [14]).

Regarding the cataloging practices of meteorite collections, both in museums and in research institutions, a notable lack of shared methodologies can be observed. Although databases such as MetBase [15] and NASA’s Astromat [16], which have recently merged [17], employed well-defined data schemas, and guidelines exist for the curation of astromaterial collections primarily intended for research purposes [18–20], standardized frameworks specifically addressing cataloging are largely absent. At present, the widely recognized models are those issued by the Meteoritical Society, the body responsible for the official approval of new meteorites [21]. These models pertain exclusively to two procedural contexts: the submission of requests for the naming of specimens recovered in

dense collection areas (e.g., [22,23]) (Table A1), and the formal procedure required for the recognition and approval of new meteorites (Table A2). The latter process culminates in the publication of the approved entries in the Meteoritical Bulletin Database, which serves as the authoritative global reference for meteorite nomenclature and classification [24]. Once published, the record is typically revised only in cases where subsequent investigations require modifications to the scientific classification of the specimen, while other descriptive and curatorial data generally remain unchanged.

Based on the above considerations, it becomes increasingly evident that natural history museums and scientific institutions preserving meteorite collections, particularly those of historical significance, must be provided with standardized cataloging models and guidelines. The adoption of shared frameworks is necessary not only to guarantee the consistency and interoperability of data across different repositories but also to safeguard the long-term accessibility and reusability of such information for both research and conservation purposes. The standards should be developed and implemented at a national level, thus ensuring that individual institutions are not left to rely solely on local solutions, which often lack compatibility and broader recognition.

This work is therefore devoted to the analysis and description of the Italian national standard for the cataloging of meteorite museum collections. The BNPL (*Beni Naturalistici–Planetologia*) model was issued in 2007 by the Central Institute for Cataloging and Documentation (ICCD), an office of the Italian Ministry of Culture [25]. Beyond its formal description, the present study will examine the adoption of BNPL across the country, evaluating its advantages and limitations. Finally, this article will consider the BNPL standard in light of emerging challenges linked to astromaterial curation practices for documentation, storage, and accessibility of planetary materials stored in both natural history museums and curation facilities.

2. The BNPL Cataloging Standard

The enactment of Legislative Decree No. 42 of 22 January 2004 (Code for Cultural Heritage and Landscape) significantly broadened the spectrum of asset categories officially recognized as cultural heritage in Italy, thereby expanding the scope of regulatory protection and management responsibilities. Among these newly recognized categories are technological heritage and natural history heritage, encompassing collections of scientific, historical, and cultural significance. The procedures and modalities for the cataloging process of cultural heritage are established by the Italian Ministry of Culture, which collaborates with regional authorities and universities in the development of methodologies and standards. This framework ensures national-level access to and processing of data, facilitating the integration of entries into the General Catalog of Cultural Heritage database (LD No. 42/2004, art. 17), the official database managed by the Italian Ministry of Culture, in which all records of Italian cultural heritage are freely accessible and available for download in open-access format [26,27].

In this context, meteorite collections, preserved in natural history museums and research institutions, are now formally acknowledged as cultural assets, underscoring the necessity of standardized cataloging and conservation practices to ensure their long-term accessibility, scientific utility, and public dissemination. In addition to the standards developed for the cataloging of geo-mineralogical and paleontological collections [28–30], whose specialized sections have already been reviewed [31], the ICCD issued the BN-PL standard in 2007 for the cataloging of planetary materials, primarily meteorites, preserved in museum collections.

The BNPL cataloging model is released in an open format on the official ICCD website [32], where it can be freely downloaded and utilized with software capable of reading

spreadsheet files. Alternatively, the model can be used within the ministerial SIGECWeb platform [33,34], which is accessible through unique credentials issued by ICCD and manages the entire cataloging workflow—from the development and dissemination of standards to the publication of records through the General Catalog of Cultural Heritage website [35]. Similarly to other ICCD cataloging standards, BNPL has been developed in full alignment with the FAIR (Findable, Accessible, Interoperable, and Reusable) principles [36]. By adhering to these principles, BNPL ensures that all metadata and records are systematically organized, readily discoverable by diverse users, interoperable with other national and international databases, and reusable for a wide range of scientific, educational, and curatorial purposes. This approach not only strengthens the transparency and reliability of meteorite documentation but also facilitates long-term preservation, data sharing, and integration into broader research infrastructures. The General Catalog of Cultural Heritage ensures wide data distribution through its Linked Open Data (LOD) services [37]. The concept of LOD refers to a set of best practices for publishing structured data on the web and interlinking them to build a global, openly accessible, and distributed data space—often referred to as the web of data [38]. Within this environment, billions of granular data points are semantically connected, allowing users to enrich individual datasets by cross-referencing information originating from different institutions, administrative bodies, or private entities. The catalog dataset can be downloaded in JSON format from the Italian Open Data portal [39], and in the forthcoming CLIO national catalog system, data accessibility will be further enhanced through dedicated APIs. Interoperability is ensured through extensive semantic alignment operations with domain-specific ontologies, including CIDOC-CRM and the Europeana Data Model (EDM) [40,41], as well as other conceptual models widely adopted in bibliographic and cultural heritage contexts, such as BIBFRAME and RiC-O [42,43]. The BNPL catalog standard is mapped within the ArCo ontology [44], which serves as a foundational conceptual framework for the future CLIO national catalog system. ArCo is a comprehensive network of ontologies designed to model the rich semantic complexity of Italian cultural heritage. By leveraging ArCo, the BNPL schema can be semantically situated within a broader, well-structured knowledge graph, facilitating data interoperability and integration across different domains. Through this mapping, each BNPL record can be expressed in RDF (Resource Description Framework), enabling its transformation into LOD that aligns with other ontologies in the cultural heritage domain. This semantic alignment ensures that the BNPL data is machine-readable and interoperable. In addition, ArCo supports a knowledge-graph approach. The new CLIO catalog system will exploit this knowledge graph to represent each cultural heritage entity as nodes interconnected via semantically rich relationships. By embedding BNPL in ArCo, the catalog benefits from a scalable and modular architecture: ArCo's ontologies are incrementally developed and publicly released under open licenses, with versioning managed on GitHub. Finally, this integration enables powerful functionalities such as SPARQL querying, semantic reasoning, and data linking, thereby facilitating advanced applications—ranging from research tools to digital exhibitions—while contributing to a dynamic, semantically interconnected “web of knowledge”.

The BN-PL catalog standard is structured into 21 sections, comprising over 500 individual metadata fields. Table A3 offers a structured overview of all sections included in the BN-PL standard, emphasizing the most relevant fields. For detailed guidance on the procedures and criteria regarding the application of the standard, reference should be made to the pertinent normative documents, which define the methodological and formal requirements for its proper compilation [25]. The BNPL cataloging standard is currently available in its 3.01 release, which already provides a robust framework for documenting extraterrestrial materials. Nevertheless, future developments are expected to align the stan-

dard with the most recent updates of other ICCD cataloging protocols, specifically version 4.01. In addition to these structural updates, the BNPL standard could be further enriched through the integration of newly adopted meteorite classification schemes (e.g., [45]) and advanced analytical datasets. For example, recent years have witnessed the establishment of new isotopic investigations—particularly nucleosynthetic anomaly data for elements such as Cr, Ti, and Fe—as routine tools in meteoritics, offering refined insights into early Solar System reservoirs. Similarly, the incorporation of state-of-the-art geochronological techniques, including Re–Os and Lu–Hf isotopic systems, would allow catalog records to better capture the temporal evolution of meteoritic materials. The progressive expansion of the BNPL standard in this direction would enhance not only the scientific depth of the catalog but also its long-term value as a dynamic repository of planetary materials research.

Beyond the systematics sections, which gather all the information necessary to achieve a reliable taxonomic classification of the meteorite, Table A3 also illustrates a broad range of additional sections that collectively ensure proper curation and long-term heritage management. These sections address crucial aspects such as conservation practices, the outcomes of analytical investigations, and the detailed description of the specimen, including the inventory numbers used in the museums preserving the specimens, as well as the systematic recording of tags, labels, and associated metadata. In this regard, the presence of local inventory numbers constitutes a fundamental element in facilitating scientific collaboration and specimen loans between researchers and institutions. These identifiers provide unambiguous references to specific specimens, thereby formally acknowledging their existence and precise location within a collection. This data is particularly valuable for researchers who wish to access or request specimens from institutions that may not maintain fully digitized or publicly available inventories. By referencing the inventory numbers, researchers can directly contact the relevant institutions to arrange loans or consultations, ensuring efficient communication and fostering collaboration. Further subsections are devoted to documenting the administrative and geographic information related to the institution responsible for preserving the sample, thereby ensuring transparency and traceability in custodianship. Notably, Table A3 also includes a section dedicated to the economic appraisal of the specimen, which highlights the multifaceted nature of meteorite heritage, encompassing not only its scientific and cultural significance but also its material and economic dimensions. However, although the cataloging records are freely accessible and downloadable from the General Catalog of Cultural Heritage database, this does not imply that all categories of information—such as those concerning economic evaluation, georeferencing, and ownership—are made available without restrictions. In fact, the various sections constituting the BNPL catalog model are subject to differentiated levels (Table A3). These range from level 0 up to level 3. Level 0 refers to data that are present in the record, but are never accessible to the general public (i.e., data relating to the economic evaluation of the sample) and remain restricted to the Italian Ministry of Culture and institutions responsible for preserving the specimens. Level 3, is assigned to specimens insufficiently safeguarded and thus exposed to the risk of theft or damage. When level 3 is selected, sensitive information (i.e., the precise geographical location where the specimens are kept) is withheld. Information that is not publicly accessible can nonetheless be consulted upon request by qualified scholars. Researchers who submit a formal request to the ICCD may be granted permission to review the restricted data, ensuring controlled access to detailed cataloging information for research purposes.

Concerning the methodology for compiling a BNPL catalog card [25], it should be emphasized that not every section of the model is obligatory. To render a card formally valid, it is sufficient to complete the mandatory fields that constitute the inventory catalog level (level I) and that are shown in Table A3. This level guarantees the registration of the essential

information required to recognize and describe the specimen, both scientifically and from a heritage perspective. The cataloger, however, may go further by filling in the non-mandatory fields. Doing so allows the record to reach the pre-catalog level (level P), where additional details enrich the descriptive and contextual framework of the specimen. When the model is completed in its entirety, including bibliographic references and supporting documentation, the record attains the catalog level (level C), which provides the fullest possible representation of the specimen within the database. A further element of particular importance is the requirement to attach at least one photographic image. This image must include a metric reference, ensuring not only a realistic visual rendering of the object but also enabling accurate scientific comparisons and verifications across collections and institutions.

Another particularly significant aspect of the BNPL compiling methodology lies in the adoption of controlled vocabularies for several sections of the model, most notably those dedicated to systematics (e.g., meteorite class and group). By requiring catalogers to select terms from predefined lists, the system reduces the risk of terminological variation, typographical errors, or subjective interpretations, thereby ensuring that entries remain consistent and comparable across different institutions and collections. This practice is essential not only for maintaining internal coherence within the General Catalog of Cultural Heritage database but also for enabling interoperability with other national and international cataloging systems, which often rely on standardized descriptors for effective data exchange and integration. In addition to controlled vocabulary, every field in the model is subject to a character limit. While this may appear to be a technical constraint, it plays a crucial role in standardizing the structure of the information provided. By restricting the length of entries, the methodology discourages overly discursive or interpretive descriptions, promoting instead concise and objective formulations. This enhances the clarity and reliability of the data, facilitates automated indexing and retrieval processes, and improves the long-term sustainability of the digital archive. Both controlled vocabularies and character limits reflect a broader strategy aimed at balancing scientific accuracy, curatorial needs, and digital interoperability, ensuring that the General Catalog of Cultural Heritage remains a robust and versatile tool for heritage documentation and research. In this regard, it is important to note that catalogued records are not static entities but may be progressively revised and expanded. Upon formal request submitted to the ICCD, the information associated with each specimen can be updated to reflect any changes that may occur over time, whether related to its physical state, provenance, curatorial history, scientific interpretations, exhibitions and loans, or any newly available metadata. Furthermore, owing to the multi-instance nature of many paragraphs and fields within the standard—meaning that these sections can be duplicated to incorporate new information without overwriting or removing previous entries—all data (e.g., conservation conditions or mislabeling cases have been reported after loan returns [46], remain fully documented. This structural feature ensures the construction of a continuous, traceable, and comprehensive documentation history for each specimen, thereby enhancing the reliability and long-term research value of the catalog.

In summary, the BNPL cataloging methodology combines mandatory and optional fields, controlled vocabularies, character limits, and differentiated visibility levels to guarantee both scientific rigor and heritage-oriented management of meteorite specimens. These features reflect a systematic effort to balance accuracy, accessibility, and interoperability within the framework of national cultural heritage documentation. Having outlined the structure and rationale of the model, the following section will examine its practical adoption, assessing the extent to which the BNPL national cataloging standard has been implemented in the case of meteorite collections.

Having outlined the structure and rationale of the BNPL national standard, the following section is dedicated to examining its practical adoption within the country. The assessment aims to determine the extent to which this model has been implemented and integrated into everyday curatorial practice for meteorite collections. The evaluation is based on a systematic review of the entries accessible through the General Catalog of Cultural Heritage database, which provides a comprehensive and publicly navigable representation of the cataloged specimens using the BNPL standard. The results of this analysis are presented in the following section.

3. Results

At the time of writing (November 2025), the General Catalog of Cultural Heritage comprises a total of 3,155,980 entries spanning a wide spectrum of categories (Table A4). Naturalistic heritage accounts for 73,003 entries, representing roughly 2% of the total items. Within this category, mineralogical heritage is the most substantial, with 41,999 records, followed by paleontological specimens (12,131), zoological specimens (8090), botanical specimens (6264), physical anthropology (2698), planetology (1153), and petrology (667) (Figure 1).

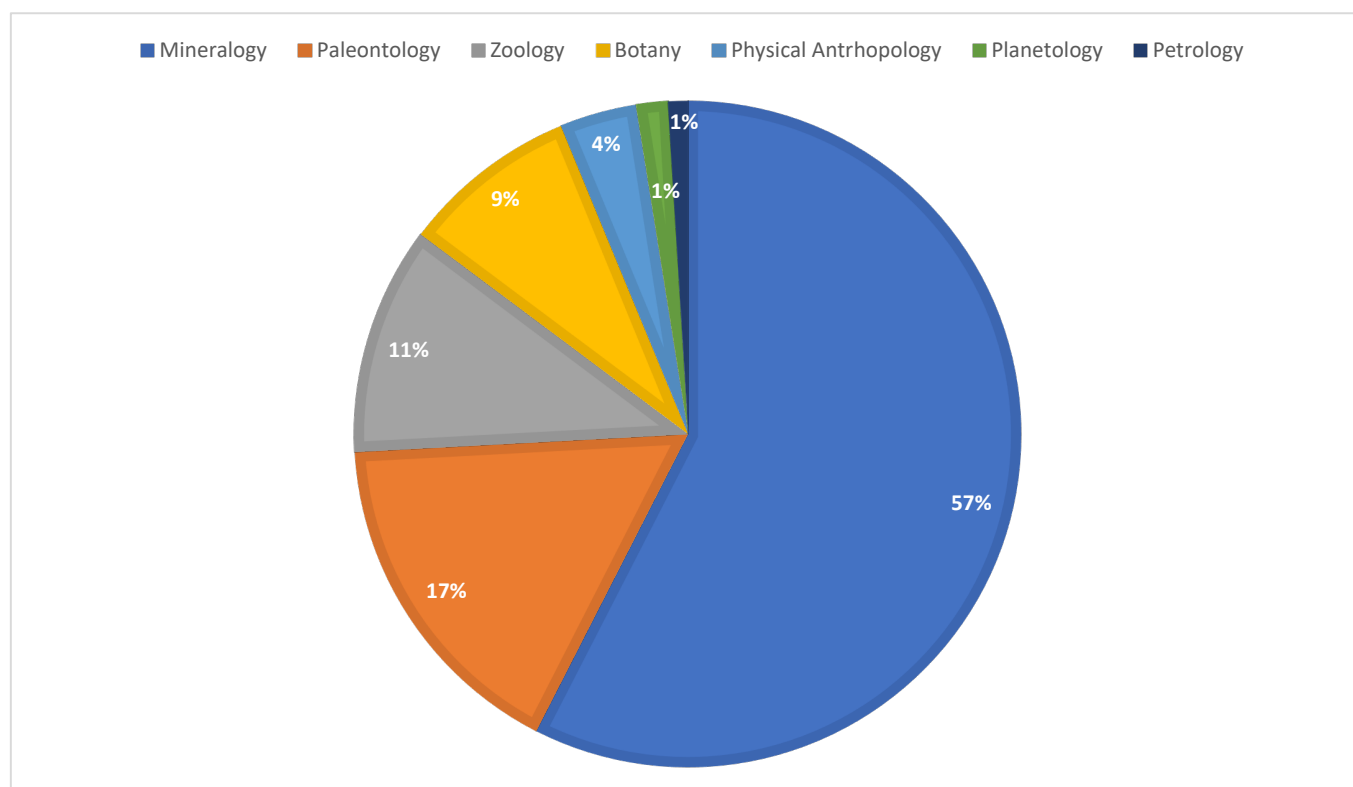


Figure 1. Cataloged Italian Naturalistic Heritage as of November 2025. Data source: General catalog of Cultural Heritage database.

According to the data shown in Figure 1, slightly more than one thousand meteorite specimens preserved in Italian museums have been cataloged to date using the BNPL national standard. It should be noted that the cataloged specimens originate exclusively from just two of Italy's twenty regions, namely Tuscany (1043) and Emilia-Romagna (110). The distribution of cataloged meteorites across institutions and regions is summarized in Table 1.

Table 1. Number of meteorites cataloged by institutions using the BNPL national standard in Tuscany and Emilia-Romagna. Data source: General Catalog of Cultural Heritage database.

Region	Institution	Meteorites
Tuscany	Italian Museum of Planetary Sciences, Prato	433
Tuscany	Museum System University of Firenze	360
Tuscany	Antarctic Museum “Felice Ippolito”, Siena	250
Emilia-Romagna	Luigi Bombicci Museum, University of Bologna	110

All cataloging campaigns adhere strictly to the methodology outlined in the previous section. Each catalog card is completed to a minimum inventory level, ensuring consistency across institutions. Furthermore, every entry is accompanied by a high-quality image of the specimen, including a metric reference (e.g., Figure 2).

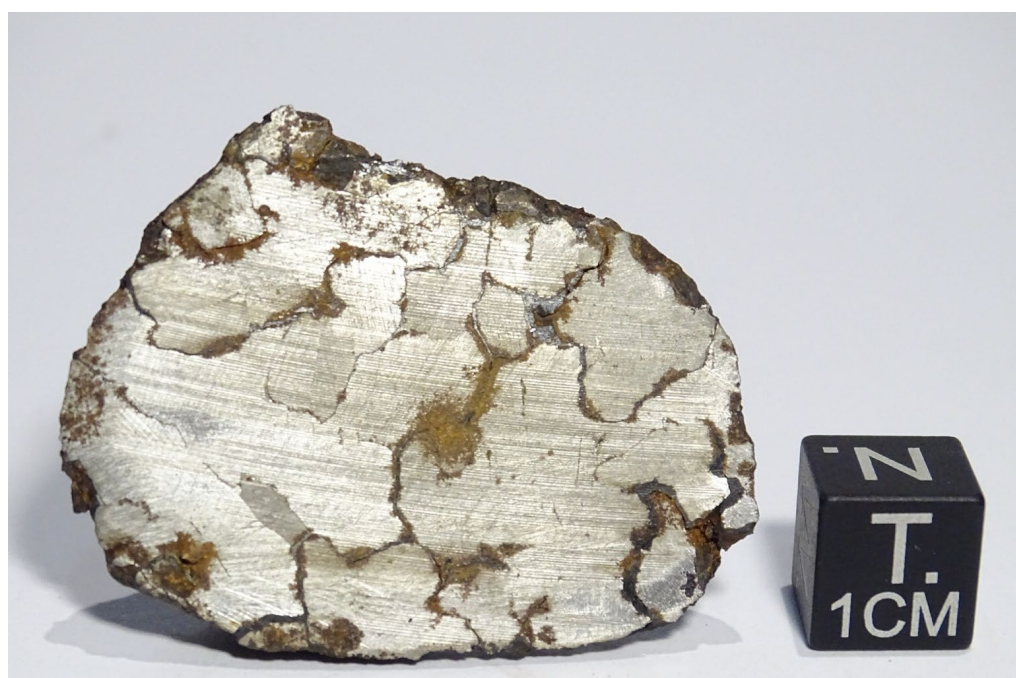


Figure 2. Example of a BNPL catalog photograph: the Castiglione del Lago meteorite, classified as Iron, IAB-MG, recovered in Umbria (Italy) in 1970. The specimen is preserved at the Italian Museum of Planetary Sciences in Prato (ICCD catalog number 0901332712). Data source: General Catalog of Cultural Heritage database.

Concerning the cataloged specimens, the University of Firenze and the Italian Museum of Planetary Sciences include both historical and newly acquired samples, reflecting their role as classification institutions and providers of related services [47]. The Antarctic Museum ‘Felice Ippolito’ in Siena presents specimens originating from the Italian Antarctic Program [48]. The Luigi Bombicci Museum of the University of Bologna, by contrast, maintains a collection composed of historical meteorites.

4. Discussion

The results derived from the analysis of meteorite entries within the General Catalog of Cultural Heritage shed light on both the strengths and the present limitations of adopting the BNPL national cataloging standard. The data show that, at the present stage, the corpus of cataloged meteorites amounts to slightly more than one thousand specimens, which is a

partial reflection of the actual extent of meteorite collections preserved in Italian museums and institutions. More strikingly, this entire dataset originates exclusively from two regions, Tuscany and Emilia-Romagna, thus revealing a highly uneven geographical distribution in the implementation of cataloging activities.

Tuscany, with three active institutions—the Antarctic Museum ‘Felice Ippolito’ in Siena, the Museum System of the University of Firenze, and I co the Italian Museum of Planetary Sciences in Prato—emerges as the leading region, responsible for most cataloged meteorites. Emilia-Romagna is represented by the Luigi Bombicci Museum of the University of Bologna. The limited territorial adoption presents several implications. Italy hosts a substantial number of natural history museums distributed across universities, regional institutions, and local civic museums. According to data collected by the National Institute of Statistics (ISTAT) for the year 2022 [49], the Italian museum system includes 261 museums and similar institutions whose prevalent typology is classified as “Natural history and natural sciences,” as illustrated in Table 2.

Table 2. Number of institutions classified as natural history and natural sciences museums in Italy, grouped by region, as of 2022. Da source: ISTAT.

Region	Natural History and Natural Sciences Museums (n.)
Piemonte	26
Valle d’Aosta	7
Lombardia	29
Trentino-Alto Adige	15
Veneto	25
Friuli-Venezia Giulia	9
Liguria	6
Emilia-Romagna	34
Toscana	22
Umbria	9
Marche	13
Lazio	10
Abruzzo	6
Molise	2
Campania	10
Puglia	7
Basilicata	1
Calabria	8
Sicilia	15
Sardegna	7

While the overall number of institutions dedicated to natural history and natural sciences is ascertainable, a comprehensive evaluation of the size and content of their specialized collections remains challenging. According to the Italian Institute for Environmental Protection and Research (ISPRA), 98 museums across Italy curate litho-mineralogical collections (Figure 3), whereas Martino [50] reported that approximately 15.4% of Italian university museum collections are devoted to Earth sciences. Within this context, the literature reports the presence of meteorite collections in diverse Italian natural history museums such as the Natural History and Civic Planetarium “Ulrico Hoepli” in Milano [51], which houses a collection of over 240 specimens and has recently been reopened to the public [52]; the Regional Museum of Natural Sciences in Turin (107 specimens) [53]; the Mineralogy and Petrography Museum of the University of Pavia (ca. 20 specimens) [54], the Natural History Museum of the University of Pisa (30 specimens of 26 individual meteorites as of June 2003 [55,56]); and the Mineralogical Museum of the University “La Sapienza” in Rome (360 specimens representing 211 individual meteorites [57]). The literature also highlights

the existence of a private meteorite collection recently acquired by the Gemellaro Museum of the University of Palermo [58] as well as the presence of historic specimens within Alberto Pelloux's (1868–1948) mineralogical collections kept at the Earth Sciences Museum of the Bari University [59]. Additional historically and scientifically important meteorite specimens are preserved at the Royal Mineralogical Museum of the University "Federico II" of Napoli, including the collection of the naturalist Teodoro Monticelli (1759–1845) [60], as well as at the Mineralogical Museum "Leonardo de Prunner" of the University of Cagliari, which houses fragments of the Sinnai meteorite that fell in Sardinia on 19 February 1956 [61]. Finally, meteorite specimens are also recorded within regional cataloging repositories [62], including those belonging to the Museum of Earth and Sky located in San Giovanni in Persiceto (Bologna) [63].



Figure 3. Geographic distribution of museums and institutions in Italy that preserve litho-mineralogical collections, based on data from ISPRA.

Based on the above, meteorite museum collections, besides those already listed in the General Catalog of Cultural Heritage, are indeed known to exist in other Italian institutions and regions; however, the absence of standardized cataloging practices means that most of these collections remain documented only through internal museum records and databases or scattered references in the literature. At present, no consolidated inter-institutional

databases exist that would allow for a systematic assessment of the number, typology, and distribution of these specimens.

The restricted territorial implementation of the BNPL cataloging model, therefore, entails a number of noteworthy implications. From a scientific perspective, the restricted dataset does not yet provide a reliable overview of the diversity and distribution of meteorite museum collections across Italy. From a heritage-management point of view, the absence of cataloged records from most Italian regions raises concerns about the risk of under-documentation, inconsistent preservation standards, and, in certain cases, reduced visibility for collections that may already suffer from limited public exposure. Such gaps diminish the potential of the BNPL national standard to serve as a tool for knowledge, conservation, and accessibility, hindering not only the establishment of a harmonized national framework but also limiting the potential for comprehensive analyses, cross-regional assessments, and large-scale integrative studies on the Italian extraterrestrial material heritage.

Table 3 presents a cross-SWOT analysis of the BNPL national cataloging standard, providing an integrated perspective on the internal and external factors that influence its effectiveness, adoption, and long-term sustainability. By examining the interactions between Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T), this framework helps identify strategic actions to reinforce its adoption and mitigate critical challenges.

Table 3. Cross-SWOT analysis of the BNPL national cataloging standard.

Strengths (S)	Weaknesses (W)
S1. Standardized methodology aligned with ICCD ministerial protocols, enabling national uniformity.	W1. Incomplete national adoption, with significant regional gaps
S2. Structured data fields and controlled vocabularies ensure consistent documentation	W2. Lack of a coordinated national cataloging campaign.
S3. Different levels to visualize sensitive information from different users	W3. Restricted information requires institutional credentials to be visualized
S4. Recursive fields to update data regarding various domains (e.g., systematics, labels, loans)	W4. Training and expertise requirements for correct usage
S5. Mandatory high-quality photographic documentation enhances reproducibility.	W5. Variable quantity and quality of previous inventories and pre-existing dataset
S6. Full compatibility with the General Catalog of Cultural Heritage database for long-term preservation and integration	
S7. Download the catalog records in Open Access from the General Catalog of Cultural Heritage database	
Opportunities (O)	Threats (T)
O1. Comprehensive national campaign of the extraterrestrial material	T1. Institutional inequalities in resources and infrastructure
O2. Growing interest in planetary sciences and geo-heritage	T2. Budget constraints affecting cataloging capacity.
O3. Integration into educational platforms and outreach programs.	T3. Technological obsolescence of external platforms if updates are not maintained
O4. Funding for digital heritage and scientific communication.	T4. Risk of parallel, non-standard documentation systems
O5. Potential for inter-institutional consortia and shared campaigns	T5. Risk of deterioration or data loss of uncatalogued collections

Table 3. *Cont.*

Cross-Strategy	Action Focus
S–O. Strategies (use strengths to exploit opportunities)	S01. Leverage BNPL standard integration to connect meteorite collections to existing databases (e.g., Astromat) S02. Use of standardized documentation for educational and outreach tools S03. Use of catalog records to valorize minor meteorite collections
S–T. Strategies (use strengths to mitigate threats)	ST1. Promote the usage of BNPL standard to prevent data fragmentation ST2. Use controlled vocabularies and recursive fields to counter ST3. Rely on General Catalog of Cultural Heritage and SIGECweb as central infrastructures to mitigate technological risks.
W–O. Strategies (Reduce weaknesses by exploiting opportunities)	WO1. Utilize national funding programs to support a coordinated cataloging campaign WO2. Expand training initiatives to improve expertise in under-resourced institutions WO3. Engage with educational/citizen-science initiatives to encourage adoption in non-participating regions
W–T. Strategies (Reduce weaknesses to avoid threats)	WT1. Improve national adoption to prevent deterioration or data loss of undocumented collections. WT2. Improve usability to reduce the likelihood of competing standards being used WT3. Strengthen documentation practices to protect heritage in unstable institutional contexts

The SWOT analysis highlights the considerable potential of adopting a unified national standard for cataloging extraterrestrial materials, while simultaneously revealing the structural weaknesses and external threats that could undermine its long-term effectiveness. The strengths identified—such as alignment with ICCD ministerial protocols, the presence of controlled vocabularies, recursive fields for continuous updates, and full interoperability with the General Catalog of Cultural Heritage database—demonstrate the significant advantages of a standardized, scientifically robust documentation framework. However, these strengths are counterbalanced by notable weaknesses, including incomplete national adoption, uneven institutional expertise, and the absence of a coordinated cataloging strategy, all of which remain critical barriers to achieving a comprehensive documentation of the Italian extraterrestrial material heritage. Opportunities such as increasing public and academic interest in planetary sciences and the potential for inter-institutional consortia underscore the timely relevance of initiating a structured, nationwide cataloging campaign. At the same time, threats—including technological obsolescence and the persistent risk of data loss—reinforce the urgency of establishing training programs capable of building technical capacity across diverse institutions. Taken together, these factors demonstrate that a coordinated national effort—combining large-scale cataloging initiatives with sustained training and professional development—is essential not only to ensure the long-term preservation and accessibility of meteorite collections, but also to secure their scientific, educational, and societal value over time. In this context, it is important to recall that the cataloging of museum-held heritage in accordance with the national standards for the documentation of Italian cultural heritage is mandated by law (Art. 17, Legislative Decree No. 42/2004). Furthermore, the systematic and standardized cataloging of collections constitutes one of the essential criteria for an institution to obtain formal recognition as part

of the National Museum System, as established by Ministerial Decree 113 of 21 February 2018. In addition to the requirement to comply with legislative regulations, the promotion of standardized cataloging can be further encouraged through participation in national initiatives. For example, the University Museum System of Firenze advanced the standardized cataloging of its geo-mineralogical collections through its participation in the Rete Italiana dei Musei Universitari (Network of Italian University Museums). This network represents a pioneering national initiative that unites twelve university museums from across Italy to foster scientific culture, promoting institutional collaboration, and supporting educational innovation. By encouraging the adoption of national cataloging standards, the network has played a key role in enhancing the consistency, accessibility, and scholarly value of academic museum collections throughout the country [64]. Expanding the cataloging coverage of the BNPL standard is thus a necessary step not only for safeguarding meteorite collections but also for consolidating the narratives that connect these extraterrestrial materials to broader questions of science, culture, and heritage. Within the Italian context, such an initiative would not only ensure the systematic preservation of meteorites but also promote their valorization as objects of both scientific inquiry and cultural heritage. In this way, Italy would enhance the capacity of its institutions to safeguard these materials while simultaneously fostering their accessibility for research, education, and public engagement. For example, the BNPL cataloging dataset could be adopted for educational platforms that contextualize planetary processes in more accessible ways for students, teachers, and the general public. Beyond these applications, BNPL catalog records offer substantial potential to support STEM (Science, Technology, Engineering, Mathematics) education more broadly. The structured, standardized documentation of meteorites creates a high-quality dataset that can be integrated into digital learning environments, virtual collections, and inquiry-based teaching modules. Moreover, the use of BNPL-formatted datasets in conjunction with artificial intelligence (AI) tools such as Cat-IA [65] opens new avenues for educational innovation, enabling semantic search and data-driven exploration within the catalog records.

On the international stage, this effort would position Italy to engage more substantively in the broader discourse on shared scientific and cultural heritage, a discourse that has been actively advanced by other European nations, including France, Germany, Austria, and the United Kingdom [66–69]. In these countries, most meteorite specimens and associated documentation are curated within national natural history museums, whose centralized databases function as critical nodes for the aggregation, dissemination, and global accessibility of data (e.g., [70]). Adopting the BNPL while engaging with transnational networks, Italy will not only safeguard its meteorite museum collections but also maximize the long-term scientific, cultural, and institutional value of these materials.

As stated above, a national cataloging framework ensures methodological consistency across different repositories, facilitating accurate documentation, standardized metadata, and comprehensive data preservation. Such an approach enables seamless integration of historical and newly acquired or classified specimens, supports the verification and traceability of research findings, and strengthens institutional accountability. In this regard, it is particularly noteworthy that the ongoing cataloging campaign at the University of Bologna is systematically uncovering and rendering accessible data from a collection of considerable historical and scientific importance, specifically that of the 19th-century naturalist Luigi Bombicci (1833–1903) [71,72] (Figure 4). The careful documentation of this collection not only preserves the provenance and integrity of specimens acquired during a vital period of Italian natural history but also provides contemporary researchers with critical insights into historical classification practices, acquisition networks, and the broader development of meteoritics in Italy.



Figure 4. A specimen of the Chantonay meteorite belonging to Luigi Bombicci’s meteorite collection. ICCD catalog number: 0800691690. Data source: General Catalog of Cultural Heritage database.

Improving the adoption of the BNPL national standard is then of strategic importance from the perspective of establishing a storage curation facility of planetary materials in Italy [73]. Even if the escalating costs and technical challenges have cast uncertainty on the destiny of the Mars Sample Return (MSR) program, several high-profile sample return missions, both recently completed and planned, are scheduled for the coming decades (e.g., [74–77]). These missions demonstrate that the success of sample return programs does not conclude with their landing on Earth but depends critically on the infrastructures that ensure their long-term preservation, standardized cataloging, and accessibility, such as those already established in the United States and Japan (e.g., [78]). A comprehensive examination of cataloging protocols specifically developed for returned samples lies beyond the scope of the present review, which is primarily focused on surveying the current state of meteorite documentation in Italian museum collections using the BNPL national cataloging standard. Nevertheless, readers interested in the methodological and procedural aspects of returned-sample cataloging, including the MSR-related protocols, may refer to the following studies, which offer detailed insights into current best practices in advanced curation of astromaterials (e.g., [18,79]) as well as for the documentation and management of extraterrestrial materials retrieved through sample-return missions (e.g., [79–83]).

In this scenario, the BNPL standard should be regarded as a conceptual and methodological baseline from which a more sophisticated cataloging model can be developed. While BNPL provides a coherent descriptive logic and a valuable organizational structure, its primary role in this process is to offer the initial framework upon which a dedicated system for research extraterrestrial collections can be conceived. Such a system must be capable of addressing the distinctive scientific, technical, conservation, and curatorial requirements associated with these materials preserved in scientific institutions, such as storage and curation facilities, where the long-term preservation, traceability, and accessibility of these samples will be paramount. At the same time, it is crucial to underscore that the future cataloging standard will not merely represent an extension or adaptation of BNPL but rather the establishment of an entirely new, autonomous, and purpose-built framework. Its design will be informed not only by current international best practices and experts in the field,

but also by the heritage of major past experiences and multidisciplinary initiatives—most notably the EUROCARES project [84]. By integrating these diverse strands of expertise, the emerging standard aims to provide a comprehensive, forward-looking solution capable of supporting both present and future research needs within the planetary science and meteoritics communities.

5. Conclusions

The analysis of meteorite cataloging practices in Italy demonstrates that the implementation of the BNPL national standard represents a decisive advancement in the stewardship of extraterrestrial materials. By providing a coherent and methodologically rigorous framework for documentation, classification, and long-term data preservation, BNPL ensures the traceability of meteorite specimens across Italian museums, harmonizing practices that were previously fragmented. In this regard, the cases of Firenze, Prato, Bologna, and Siena exemplify how diverse collection strategies—ranging from historical acquisitions to contemporary research-oriented sampling—can be integrated effectively within a unified documentation system, thereby enhancing both scientific reliability and institutional coordination.

Nonetheless, the full adoption of the BNPL standard for cataloging meteorite museum collections requires further refinement and the development of coordinated initiatives. These initiatives could include the establishment of targeted training programs for museum personnel, researchers, and graduate and doctoral students, fostering their active participation in the launch of new cataloging campaigns and ensuring the consistent application of best practices across institutions. Complementing these efforts, the forthcoming national storage curation facility will benefit from the experience provided by the adoption of the BNPL model during the development of its own cataloging standards and systems.

In conclusion, the improvement of the BNPL national cataloging standard will not only secure the long-term preservation and environmental protection of planetary collections but also enable enhanced monitoring, risk management, and integration of metadata across institutions, bridging the gap between conservation, valorization, and research use of the Italian meteorite heritage. Together, the combination of these approaches will facilitate interoperability of Italian cataloging datasets with global databases and the establishment of new collaborative research networks.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
API	Application Programming Interface
ArCo	Architettura della Conoscenza
BIBFRAME	Bibliographic Framework
BNPL	Beni Naturalistici–Planetologia
Cat-IA	Catalogo-Intelligenza Artificiale
CLIO	Catalogazione, Localizzazione, Identificazione, Organizzazione
EDM	Europeana Data Model
JSON	JavaScript Object Notation
ICCD	Central Institute for Catalog and Documentation
LOD	Link Open Data
INSTAT	National Institute of Statistics
ISPRA	Italian Institute for Environmental Protection and Research
MSR	Mars Sample Return
RDF	Resource Description Framework
RiC-O	Records in Contexts Ontology
STEM	Science, Technology, Engineering, Mathematics

Appendix A

Table A1. Template for requesting provisional names to the Nomenclature Committee of the Meteoritical Society for new meteorites found in dense collection areas. Fields have been grouped into four sections. Fields marked with an asterisk (*) are mandatory.

Template for Requesting Provisional Names		
Section	Field	Description/Notes
Proposed Identification	Proposed name *	Name/abbreviation of the collection area where the specimen was found
Discovery/Origin	Field name *	Local field or find name
	Origin	Country/region where specimen was recovered
	Latitude	Geographic latitude of find site
	Longitude	Geographic longitude of find site
Collection data	Purchased	Indicate the place if acquire through purchase
	Date *	Date of discovery/acquisition
	Mass *	Total recovered mass
	Pieces	Number of individual specimens or fragments
Specimen Information	Specimens *	Location and mass of the type specimens
	Description *	General description of the specimen
	Info	Additional information about the specimen or submitter's contact data
Administrative	Assigned to	Submitter's name
	Assigned by	Automatic

Table A2. Template for submitting new meteorites to the Nomenclature Committee of the Meteoritical Society. Fields have been grouped into seven sections. Fields marked with an asterisk (*) are mandatory.

Template for the Submission of New Meteorites		
Section	Field	Description/Notes
Identification	Proposed name *	Proposed name for the specimen or the provisional name
Geographic information	Country	Country where the specimen was recovered
	State/Province	State/Province where the specimen was found
	Site	Description of the setting where the specimen fell or was found
	Latitude	Geographic latitude of find site
	Longitude	Geographic longitude of find site
Recovery Context	Find or Fall Date	Date that the specimen fell or was discovered
	Fall	C for confirmed fall, P for probable Fall, S for Find, Possible Fall, D for Find, doubtful Fall, or Y for fall no suggestion
	Purchase Date	If purchased, provide acquisition date
	Purchase Place	Location of acquisition
Physical Data	Mass *	Total mass of the specimen including fragments
	Pieces *	Number of the recovered specimens/Descriptive words as “many”
Systematics	Class *	Specimen classification
	Shock	Shock stage
	Weathering grade	Degree of terrestrial weathering
	Fa	Fayalite content of olivine in mol%
	Fs	Ferrosilite content of pyroxene, calculated from Fe-Mg-Ca endmembers, in mol%
	Wo	Wollastonite content of pyroxene, calculated from Fe-Mg-Ca endmembers, in mol%
	Mag sus	Magnetic susceptibility
	Writeup physical	Description of the specimen’s physical characteristics
	Writeup petrog	Petrographic description
	Writeup geochem	Geochemical description
	Writeup class	Classification description
Curation	Type spec mass *	Type specimen(s) mass
	Type spec loc *	Name or abbreviation of the institution where the type specimen has been deposited
	Main mass loc *	Location/name of the owner of the main mass
	Writeup specimens	List the weight and location of the most significant specimens
	Writeup history	History of the recovered specimens
	Finder	Name of the person(s) who discovered the specimen
	Comments	General remarks
Administrative	Classifier *	Name(s) of the classifier(s)
	Submitter *	Name of the submitter

Table A3. Most relevant fields for the BNPL Italian national cataloging standard for museum meteorite collections. Fields marked with an asterisk (*) are mandatory.

BNPL			
Visibility	Section	Field	Description/Notes
1	Object	Definition *	Describe the type of meteorite according to the literature (e.g., Martian, aubrite, etc.)
		Identification	Specify if the specimen is an individual or is part of a series/collection
		Container	Specify the container or support, if any, in which the meteorite is currently preserved
1	Quantity	Number	Record the number of individual specimens, if greater than one
1	Systematics	Nomenclature	
		Name	Enter the official meteorite name as reported in the Meteoritical Bulletin Database
		Type	Meteorite type
		Class	Meteorite classification
		Group	Meteorite group
		Petrologic Type	Meteorite petrologic type
		Fall/Find	Specify whether the meteorite is a find or a fall
		Date	Specify the date of the fall or the recovery of the first fragment
		Type specimen location	Indicate the institution preserving the type specimen
		Type specimen weight	Weight of the type specimen
		Main mass location	Specify the institution responsible for preserving the main mass, or the name of the collector.
		Main mass weight	Weight of the main mass
		Total known weight	Record the meteorite's total known weight
1	Petrography	Shock grade	Meteorite shock grade
		Texture	Meteorite texture
		Weathering grade	Meteorite weathering grade
		Chondrule/matrix ratio	Specify the ratio of chondrules to matrix in terms of volume percent (vol%)
		Chondrule type	Report the predominant chondrule type(s) in the specimen
1	Mineralogy	Fayalite (mol%)	Indicate the average composition of olivine in the sample, expressed as mole percent of fayalite
		Ferrosilite (mol%)	Report the mean orthopyroxene composition in the sample, in terms of ferrosilite mole percent
		Anorthite (mol%)	Indicate the average composition of plagioclase in the sample, expressed as mole percent of anorthite
		Olivine (vol%)	Indicate the modal percentage of olivine (vol%)
		Pyroxene (vol%)	Indicate the modal percentage of orthopyroxene (vol%)
		Plagioclase (vol%)	Indicate the modal percentage of plagioclase (vol%)
		Metal (vol%)	Indicate the modal percentage of metal (vol%)
1	Oxygen isotopes	Sulphides (vol%)	Indicate the modal percentage of sulphides (vol%)
		$\delta^{17}\text{O}$	
		$\delta^{18}\text{O}$	
		$\Delta^{17}\text{O}$	

Table A3. Cont.

BNPL			
Visibility	Section	Field	Description/Notes
1	Geochronology	Igneous age 87 Rb/86 Sr 147 Sm/144 Nd 147 Sm/144 Nd 238 U/206 Pb Shock age 87 Rb/86 Sr 40 Ar/40 K Cosmic ray exposure age 3 He 21 Ne 38 Ar Terrestrial Age 14 C 10 Be 36 Cl	Indicate the age of the rock, that is, the time elapsed since the solidification of the parental melt Express the age of the metamorphic event resulting from shock experienced by the meteorite The cosmic-ray exposure age (CREA) is a measure of how long a meteorite has traveled through interplanetary space, remaining exposed to cosmic rays from the Sun and the Galaxy The terrestrial age of a meteorite is a measure of the time the meteorite has resided on Earth
1	Additional information	Availability of sample portions Availability thin sections Availability of grains	
1	Type	Type Author Reference	Indicate if the meteorite is a holotype Indicate the name(s) of the classifier(s) Specify the biographic reference of the meteorite's classification
1	Tags/Labels	Text Notes	Report the text of the label(s), tag(s) Additional information about tag(s), label(s)
1	Field data	Location/Continent/ Country	Specify the information about the location where the meteorite was collected
1	Recovery data	Date/Collector/ Principal investigator	Information regarding the collection date and the collector, as well as the reasons and methods that led to the collection of
1	Past classification	Systematics, Petrology, Mineralogy, Oxygen isotopes, Geochronology, Type, Additional information, tags/labels	Reporting previous meteorite's classification data, if any
1–3	Geographic and Administrative Location *		Data regarding the geographic and administrative location of the meteorite at the time the record is compiled
1–3	Past geographic and administrative location(s)		Information regarding past geographic and administrative location of the meteorite

Table A3. *Cont.*

BNPL			
Visibility	Section	Field	Description/Notes
0–1	Collection and economic data	Inventory Valuation	Meteorite inventory number (preserving institution) Indicate the economic value of the meteorite Provide details regarding the current collection and any historical collections of which the meteorite is or has been a part
3	Collection		
	Point-based georeferencing		Provide information allowing the georeferencing of both the original collection site and the current location of the meteorite
1	Technical data	Measurements	Data about the specimen's size
1	Analytical data	Physical description, historical notes	Detailed information on the meteorite
1	Conservation *	State, type, modalities	Provide information on the conservation condition of the cataloged item
1	Restoration/Analyses		Provide details of any restoration work performed and laboratory analyses conducted on the meteorite.
1–2	Legal status/regulatory constraints *		Provide details regarding the item's ownership, relevant legal protections, and any transfers of ownership
1–2	References and sources	Photos *, graphs, audio-videos, archival documents, books, exhibitions	Information on documentary sources and on photographic, graphic, multimedia, and bibliographic references, including exhibitions (if any)
1	Data access *	Data access profile	Information regarding access to the data, ranging from fully accessible (1) to restricted (3)
1	Notes	General remarks	

Table A4. Data pertaining to the categories of the Italian General Catalog of Cultural Heritage, which documents the nation's cultural assets managed under the Ministry of Culture. The table represents the number of cataloged records for each heritage category.

Category	Number of Records
Works of art	2,219,767
Archeology	407,777
Photography	223,081
Architecture and landscape	101,596
Naturalistic heritage	73,003
Material and immaterial demo-ethno-anthropological heritage	77,561
Numismatic	40,304
Technological and scientific heritage	16,914
Musical instruments	1977

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