Original Russian Text: Plechov P.Yu., Konovalova K.A., 2023, published in Novyye Dannyye o Mineralakh, 2023, №. 4, iss. 1, pp. 92-102, doi: 10.25993/FM.2023.57.2023.010

Elecrtonic version is available on
https://fmm.ru/Journal/NDM57_2023_eng
Fersman Mineralogical Museum RAS

New data on minerals, V. 57, iss. 4 (2023), 92–102

NDM

The status of the meteorite collection at the Mineralogical Museum of the Russian Academy of Sciences

Plechov P.Yu., Konovalova K.A.

Fersman Mineralogical Museum, Moscow, Russia, pplechov@gmail.com

This paper presents an extensive review of the meteorite collection preserved at the Fersman Mineralogical Museum of the Russian Academy of Sciences, highlighting significant findings from a scientific revision of the collection. The collection, with a rich and complex history, includes meteorites and impactites, some of which date back to the 18th century. Recent efforts have revitalized the collection, emphasizing the importance of meteoritic material in mineralogical studies, as over hundred minerals were first discovered in meteorites. Currently, the collection consists of 247 samples, including 44 registration masses of newly discovered meteorites. The paper discusses the representativeness of the collection for exhibition and research purposes, detailing the variety of meteoritic minerals and their implications for scientific study. It delves into the challenges and future directions for enhancing the collection, including the acquisition of rare meteorite types and continuous research and registration of new meteoritic material. The paper also sheds light on the museum's approach to expanding and maintaining the collection, through active research collaborations and participation in meteorite expeditions. This study contributes significantly to understanding the diversity and scientific value of meteoritic collections in museums, underscoring their role in advancing mineralogical knowledge.

Keywords: meteorite collection, pallasite, chondrite, carbonaceous chondrite, mesosiderite, achondrite, Fersman Mineralogical Museum.

Introduction

The meteorite collection of the Fersman Mineralogical Museum of the Russian Academy of Sciences has a long and complex history. The earliest specimens date back to the discoveries of the 18th century [Nazarov, 2000], and for almost 150 years, nearly all meteorite finds were transferred to the meteorite collection of the Russian Academy of Sciences, housed in the Mineralogical Museum. In 1935, at the initiative of the Museum's staff, a meteorite commission was established, led by academician A.E. Fersman, and in 1939, it was reorganized into the Meteorite Committee under the leadership of V.I. Vernadsky. The first scientific secretary of the committee was L.A. Kulik, a disciple of V.I. Vernadsky and a staff member of the Mineralogical Museum of the Russian Academy of Sciences. Later, the entire meteorite collection of the Russian Academy of Sciences was fully transferred to the Meteorite Committee. Some historical specimens remained in the exhibition of the Mineralogical Museum, but scientific work on the study of meteoritic material in the museum ceased for many years.

In the 2000s, it became conclusively clear that the Mineralogical Museum's collection could not exist without meteoritic material. Over a hundred minerals were first discovered in meteoritic material, and many of them have not yet been found in terrestrial rocks [Rubin, Ma, 2020]. The rock-forming minerals of most meteorites (such as olivine, pyroxenes, native iron, etc.), while having terrestrial analogs, possess many specific characteristics unique to meteoritic material. Recently, the decision was made to recreate the meteorite collection of the Museum. The first 39 samples were entered into the newly established meteorite collection of the Museum on January 14, 2010. This date can be considered the date of the renewed emergence of the meteorite collection of the Fersman Mineralogical Museum of the Russian Academy of Sciences, although some of these specimens had entered the Museum well before 2010. The collection has been expanding much more actively since 2018, as the Museum gained the right to register new meteorites, and a scientific group for the study of meteoritic material was established [Plechov et al., 2020].

As of November 2023, the collection comprises 247 samples of meteorites and impactites, including 44 samples that are type specimens of new meteorites registered by the Museum. Historically, meteoritic material and impactites are also present in other collections of the Museum (systematic collection – 49 samples, collection of formations and transformations – 2 samples, V.I. Stepanov's collection – 4 samples). In this article, we discuss the current state of the meteorite collection of the Fersman Mineralogical Museum of the Russian Academy of Sciences with two main goals: 1) to understand the representativeness of the collection for exhibition and research purposes; 2) to determine the top-priority tasks for the development of the meteorite collection.

When describing the collection, we used the information system of the Mineralogical Museum (http://www.fmm.ru/). All mineral names in Russian were cross-checked with the "Mineral Species" handbook [Krivovichev, 2021]. The number of finds of various types and groups of meteorites was determined according to the [Meteorite Bulletin Database, 2023] in November 2023.

Minerals in Meteoritic Material

A significant portion of mineral specimens (52 items) from meteoritic material is recorded in the systematic collection of the Mineralogical Museum. Primarily, these include holotypes of chukanovite ($Fe^{2+}_2(CO_3)(OH)_2$) [Pekov et al., 2007] and droninoite ($Ni_3Fe^{3+}Cl(OH)_8 \cdot 2H_2O$) [Chukanov et al., 2008], which were transferred by the authors during the registration of new minerals. Allabogdanite $(Fe,Ni)_2P$ [Britvin et al., 2002] is represented by an author's specimen from the Onello meteorite. Fourteen specimens are recorded in the collection as native iron; however, there are certain challenges when attributing a meteoritic material sample to a specific mineral. For most of these specimens, their affiliation with a specific meteorite has not been determined. For some (e.g., sample FMM_1_47188 from Disko Island), the classification as meteoritic material was made in error. Several specimens were transferred to the Meteorite Committee in 1957, and consequently, they are no longer in the Museum's collection. Most transferred specimens have corresponding entries in the inventory book, but for sample FMM_1_2243 (Chinge meteorite), there is no such record. Two samples of Sikhote-Alin meteorite are recorded as kamacite, and two samples (Niro and Xiquipilko meteorites) are recorded as taenite. Two more samples are recorded as kamacite in V.I. Stepanov's collection (one from the Sikhote-Alin meteorite, and the other found in the Moscow region, with no instrumental confirmation of its meteoritic origin). Obviously, these meteorites contain varieties of native iron other than those specified. The collection also includes one sample of tetrataenite (NWA12590 meteorite).

Schreibersite $(Fe,Ni)_3P$ is represented by five samples (two from Sikhote-Alin meteorite, two from the pallasite Seymchan, and one from the Canyon Diablo meteorite). Four of these samples are in the systematic collection, and one is in the meteorite collection. Nickelphosphide $(Ni,Fe)_3P$ is represented by only one sample from the acapulcoite NWA1054 meteorite. Carbides in meteoritic material are represented by two mineral species: haxonite $(Fe,Ni)_{23}C_6$ (sample FMM_1_92033), grains of which were isolated in assemblage with plessite in the kamacite-taenite veins of the iron meteorite Egvekinot (IICD group), and cohenite Fe_3C (sample FMM_1_88712), as microscopic inclusions around schreibersite in an etched slice of the iron meteorite Sikhote-Alin (IIAB group). The collection includes one representative of nitrides – carlsbergite CrN (sample FMM_1_92029) from the Kenton County iron meteorite (type IIIAB), one silicide – zuessite $(Fe,Ni)_3Si$ (sample FMM_1_92029) from the polymict ureilite Dar al Gani 319, and one phosphosilicide – perryite $(Ni,Fe)_5(Si,P)_2$ (sample FMM_1_92040) from the anomalous aubrite Mount Egerton.

Until 2010, only four very rare sulfides from enstatite chondrites were included in the systematic collection. These are shulamitite $Na_{0.3}CrS_2 \cdot H_2O$ (sample FMM_1_92032), niningerite $(Mg,Fe^{2+},Mn^{2+})S$ (sample FMM_1_92030), rudashevskyite (Fe,Zn)S (sample FMM_1_92031) from the Indarch meteorite (EH4 type), and keilite FeS (sample FMM_1_92037) from the Abee meteorite (EH4 type). Notably, the much more widespread daubreelite ($Fe^{2+}Cr^{3+}_2S_4$) was absent from the collection. This issue was addressed in 2018 when three researchers independently donated daubreelite specimens from the Chinge ataxite, where large daubreelite inclusions are common in association with troilite. However, troilite itself has not yet been recorded in the systematic collection, despite being characteristic of meteoritic material. In contrast, the systematic collection includes 18 troilite specimens from terrestrial objects, where it occurs much less frequently. Djerfisherite ($K_6(Fe,Cu,Ni)_{25}S_{26}Cl$), first discovered in enstatite chondrites [Fuchs, 1966], is also represented only by terrestrial specimens in our collection. Two samples of heideite $(Fe,Cr)_{1.15}(Ti,Fe)_2S_4$ were initially recorded in the Museum's catalog, but upon verification, these entries were found to be incorrect, and both samples actually belong to a completely different mineral – haydeeite $(Cu_3Mg(OH)_6C_{l2})$.

Out of seventeen oxides discovered in meteoritic material, not a single one is present in the Museum's collection. Coesite (SiO_2) is represented by two samples from the Arizona Meteor Crater (the site of its first description), two samples from the Elgygytgyn meteorite crater, and several samples from terrestrial metamorphic rocks. Stishovite (SiO_2), also first described in the Arizona Meteor Crater, is represented by only one sample (FMM_1_91990) from the Ternovka astrobleme in our collection. Alongside these, the collection includes all hydroxides (hydroxychlorides) discovered during the study of secondary alterations in meteorites. Droninoite ($Ni_6Fe^{3+}{}_2Cl_2(OH)_{16}·4H_2O$) is represented by two author's specimens, including the holotype, and muonionalustaite ($Ni_3(OH)_4Cl_2·4H_2O$) – a grain from the corrosion crust of the Muonionalusta meteorite (sample FMM_1_97688).

Oxygen salts (phosphates and carbonates) discovered in meteoritic material are also weakly represented in the Museum's collection. Out of 22 such minerals, the collection includes only one specimen each of merrillite $Ca_9NaMg(PO_4)_7$ (FMM_1_92041) and stanfieldite $Ca_4Mg_5(PO4)_6$ (FMM_1_92041) from the Bragin pallasite, as well as the holotype of chukanovite ($Fe^{2+}{}_2(CO_3)(OH)_2$) from the Dronino meteorite (FMM_1_92013). Arupite ($Ni_3(PO_4)_2·8H_2O$) and chladniite ($Na_3CaMg_{11}(PO_4)_9$) are only represented by specimens from terrestrial sources, with the chladniite specimen in the collection significantly differing from meteoritic chladniite due to its high arsenic content and virtually complete absence of iron [Pekov et al., 2023].

Silicates are characteristic of meteoritic material, except for iron meteorites. Predominantly, these are the same minerals that compose terrestrial igneous rocks, representing the forsterite-fayalite, diopside-hedenbergite, enstatite-ferrosilite, and albite-anorthite series. Discoveries of new silicates (a total of 30 mineral species) are associated with several relatively rare types of meteorites and specific objects within them. Ten new silicates were discovered in calcium-aluminum inclusions (CAI) in carbonacerous chondrites. In our collection, among these minerals, only grossmanite ($CaTi^{3+}Al[SiO_6]$) and kushiroite ($CaAl[AlSiO_6]$) from the enstatite chondrite NWA12590 are present. Fourteen high-pressure silicates were discovered in impact veins in meteorites, as well as in lunar and Martian meteorites that have undergone strong impact events. In our collection, only ringwoodite ($(Mg,Fe^{2+})_2SiO_4$), majorite $Mg_3(MgSi)(SiO_4)_3$, and lingunite ($(Na,Ca)AlSi_3O_8$) are represented from these minerals. In other types of meteorites, only six new silicates have been described. Clinoenstatite ($MgSiO_3$) is the main rock-forming mineral of enstatite chondrites and carbonaceous chondrites of petrological type 3, but all samples of enstatite chondrites in the collection are recorded for rarer minerals, and clinoenstatite is represented by terrestrial specimens. Roedderite (K(,Na) $Mg_2Mg_3[Si_{12}O_{30}]$) from the Sayh Al Uhamir 001 meteorite (L5 type) was donated to the Museum in 2018 by T.V. Kryachko. Krinovite ($Na_2Mg_4Cr^{3+}{}_2(Si_6O_{18})O_2$), colomeraite ($NaTi^{3+}Si_2O_6$), kuratite ($Ca_2(Fe^{2+}{}_5Ti)O_2[Si_4Al_2O_{18}]$), and yagiite ($(Na,Ca)_2Mg_2Al_3[Al_2Si_{10}O_{30}]$) are currently absent from the Museum's collection.

Various Types of Meteorites

Ordinary Chondrites

Ordinary chondrites constitute the most common class of meteorites both in our collection (80 specimens from 39 meteorites, see Table 1) and overall (refer to the Meteorite Bulletin Database: 56,437 registered finds as of November 2023). Ordinary chondrites are categorized into groups based on the silicate-to-metallic ratio (LL, L, and H) as well as petrological type [Kallemeyn et al., 1989, Van Schmus & Wood, 1967]. The current status of the ordinary chondrite collection is reflected in Table 1. The columns in the table correspond to the petrological type of chondrite, and the rows LL, L, and H correspond to the groups. Each cell lists the meteorites in the collection assigned to that subgroup, with the number of specimens for each meteorite indicated in parentheses. The H5 subgroup is most comprehensively represented in our collection (25 specimens from 21 meteorites). This is partially explained by the fact that six new finds registered by the Museum (Chug Chug 106-111) were discovered close to each other in the vicinity of Antofagasta (Chile) and may belong to the same meteorite.

In the Museum's collection, representatives of the rare LL3 and LL4 subgroups are currently absent. In the Meteorite Bulletin Database (2023), data for these subgroups are also represented by a minimal number of finds (488 and 392, respectively). Discoveries of large meteorites belonging to the LL3 and LL4 subgroups are described within the NWA family (Northwest Africa). The Savchenkoe meteorite (LL4, 2.5 kg, fallen in 1894 near Odessa) is stored in the meteorite collection of the Russian Academy of Sciences.

Carbonaceous Chondrites

Among the nine groups of carbonaceous chondrites [Krot et al., 2014; Metzler et al., 2021], the Museum's collection includes representatives from only four groups (10 samples from 7 meteorites). The CV3 group is the most fully represented, including Allende, NWA12590, NWA11904, and NWA8160. Attention to

Table 1. Ordinary chondrite specimens in the Museum's collection

Petrological type	3	4	5	6
LL			NWA 10244(1), Chelyabinsk (6)	NWA 12578 (1), Chug Chug 113 (1), Calama 282 (1), Chug Chug 110 (1), Toconao 007 (1), Sulagiri (Hosur) (1)
L	Aba Panu (2)	Chug Chug 014 (1), Chug Chug 044 (1)	Sayh Al Uhamir 001 (1), Ngare Sero (1), Calate 017 (1), Sierra Gorda 022 (1), NWA 11434 (1), Tsarev (2)	JJiddat Al Harasis 020 (3), Ozerki (1), Viñales (1), Potter (1), Sierra Gorda 064 (1), Dhofar 228 (1), Gold Basin (1), Ozernoe (1)
H	NWA 7123 (1), Chug Chug 096 (2)	Chug Chug 003 (1), Sierra Gorda 012 (1), NWA 13529 (1), Calama 175 (1), Dhofar (1)	Kunya-Urgench (2), Dhofar 935 (1), Calama 002 (1), Aiquile (2), Gao-Guenie (2), Calama 032 (1), Chug Chug 013 (1), Chug Chug 015 (1), Chug Chug 106 (1), Chug Chug 107 (1), Chug Chug 108 (1), Chug Chug 109 (1), Chug Chug 010 (1), Chug Chug 111 (1), Chergach (1), NWA 400 (1), Marsa Alam 033 (1), Tamdakht (1), El Hammani (1), Kharabali (2), Yaratkulova (1)	Calama 033 (1), Peekskil (1), Navoi (2), Calama 022 (1), Chug Chug 112 (1), Marsa Alam 032 (1), Calama 192 (1)

Notes: Column and row intersections correspond to groups of ordinary chondrites (LL3, LL4, LL5, etc.). The cells list the meteorites of that group, and the number of specimens available is indicated in parentheses.

this group is explained by its large number of calcium-aluminum inclusions (CAIs) containing very rare minerals (grossmanite, kushiroite, hexamolybdenum ((Mo,Ru,Fe,Ir,Os)), dmitriiivanovite (CaAl2O4), krotite (CaAl2O4), and many others. Meteorites in this group vary in oxidation state [McSween, 1977]. The least oxidized is NWA12590, which we registered as a representative of the rare CV3r (reduced) subgroup. Allende is the most studied representative of the CV3oxA subgroup. In 2022, the Museum registered a new meteorite from the CK3 group (NWA14914). Thus, the CV-CK clan is adequately represented in our collection. Among the metal-rich carbonaceous chondrites of the CB-CH clan, the Museum has only a small fragment (mass 2.86 g) of the Gujba meteorite. In 2019, a fragment of the Aguas Zarcas meteorite (mass 8.23 g), belonging to the CM2 group, was added to the Museum's collection.

The collection lacks representatives of the rare CI1 group (only 9 finds with a total mass of just under 22 kg) and the new CL group of carbonaceous chondrites (7 finds with a total mass of less than 6 kg). Finding material from these groups for the collection will be incredibly challenging. The collection also lacks meteorites from the CO (643 finds) and CR (211 finds) groups, which are more abundant, and obtaining samples from these groups for the Museum seems to be a feasible task.

Achondrites

Achondrites are highly diverse as they reflect various degrees of differentiation of primitive chondritic material. It is believed that primitive achondrites (acapulcoites, lodranites, brachinites, winonaites) underwent melting, which destroyed the chondritic structure, but significant differentiation into metallic and silicate components did not occur. Such meteorites are very rare (only 363 finds: 91 acapulcoites, 91 lodranites, 37 acapulcoite/lodranites, 58 brachinites, 86 winonaites), and unfortunately, our collection lacks them, except for one grain of acapulcoite (NWA1054) recorded as the mineral nickelphosphide (sample FMM_1_92038).

Among the differentiated achondrites, the HED group (howardites, eucrites, diogenites) stands out, which are presumed to belong to one celestial body or several bodies with a similar oxygen isotopic composition [McSween et al., 2012]. These meteorites are also referred to as "Vesta-type asteroid meteorites". The Museum's collection has only one sample each of howardites (Sariçiçek meteorite, FMM_10_76), eucrites (Dhofar 007 meteorite, FMM_10_12), and diogenites (Calama 082 meteorite, FMM_10_204).

In 2020, the Museum registered the meteorite NWA 13135, which turned out to be a monomict olivine-pigeonite ureilite. The type specimen (13.6 g) of this meteorite is recorded in the Museum's main collection as sample FMM_10_233. Ureilites with veins of high-pressure minerals (including the progenitor of this group – Novo-Urei) are absent from the collection. The collection also lacks rare achondrites from the angrite group (known 45 finds) and the aubrite group (known 87 finds), which motivates their acquisition for the collection. One grain of the aubrite Mount Egerton is recorded in the systematic collection as the mineral perryite (sample FMM_1_92040).

Planetary achondrites – Martian and lunar – are separated into a distinct group. In our collection, there are only three small fragments of lunar meteorites. All of them (Dar Al Gani 400, NWA13676, and Lahmada 020) represent feldspathic breccias – the most common group of lunar meteorites [Meteorite Bulletin Database, 2023].

Pallasites and Mesosiderites

The first meteorite for which extraterrestrial origin was proven is the famous Pallas Iron (synonym of the Krasnoyarsk meteorite). The history of studying this meteorite is inseparably linked to the Mineralogical Museum and the academician Peter Simon Pallas, who headed it in the second half of the 18th century [Nazarov, 2000]. In the 19th century, the mineralogy of Pallas Iron was studied by J. Berzelius, F. Stromeyer, A.F. Gebel, G. Rose, N.I. Koksharov, and many others [Eremeeva, 1982]. The main mass of Pallas Iron (514.5 kg), divided into two parts in the 19th century, is part of the meteorite collection of the Russian Academy of Sciences (RAS) and is exhibited in the Mineralogical Museum of the RAS. Fragments weighing up to 4 kg were separated from the main mass until 1778, and these fragments were dispersed among many museums worldwide. One such fragment is preserved in the systematic collection of the Mineralogical Museum of the RAS (Fig. 1).

Pallasites, as a class of iron-stony meteorites composed of a silicate part (predominantly large olivine grains) enclosed in a metallic mass, got their name from Pallas Iron. From a classification perspective, pallasites are divided into the main group pallasites (PMG), where the metallic mass is represented by octahedrites similar to the IIIAB group of iron meteorites. Much rarer are the Eagle Station Group pallasites (PES, only five finds in total). The PES group differs from PMG in its metallic component, which corresponds to the IIF group of iron meteorites. Additionally, the olivine in PES contains more calcium than the olivine in PMG [Wasson, Choi, 2003].

As of today, there are 170 known finds of pallasites, seven of which were discovered in the territory of Russia and Belarus [Meteorite Bulletin Database, 2023]. Samples from three of these seven pallasites (Bragin, Pallas Iron, Seymchan) are present in our collection. Furthermore, over the past seven years, specimens of foreign pallasites, Sericho (Kenya) and Imilac (Chile), have been added to the collection, and their photos are shown in Fig. 2.

The Museum's collection lacks four out of seven pallasites found in the territory of the Russian Federation and Belarus, but three of them (Karavannoye, Pallasovka, and Lipovsky Khutor) are present in the meteorite collection of the Russian Academy of Sciences. The main mass (45 kg) of the Marjalahti pallasite, fallen in 1902 in the territory of modern Karelia, is stored in the collection of the Geological Survey of Finland. The type specimen of the Karavannoye meteorite, the largest of the

Fig. 1. Sample of pallasite "Pallas Iron" (FMM_1_55305) in the systematic collection of the Mineralogical Museum.

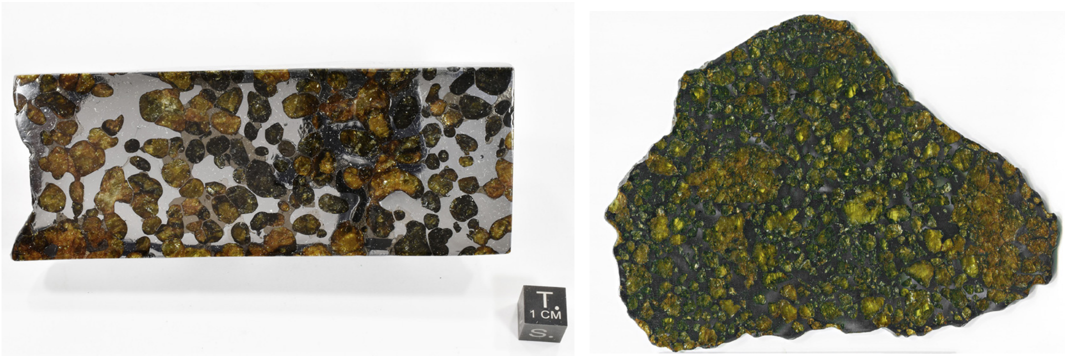

Fig. 2. Specimens of pallasites Sericho (FMM_10_202) and Imilac (FMM_10_195) in the Museum's collection. The Imilac meteorite slice measures 23.5 x 17 x 0.2 cm. Both samples were donated to the Museum by V.N. Kalachev.

registered PES finds, is kept in the meteorite collection of the RAS. Some pallasites (e.g., Vermillion and Yamato 8451) contain up to 3% orthopyroxene, and it has been proposed to classify such meteorites into a separate group called pyroxene pallasites [Bunch et al., 2005]. The total number of pyroxene pallasite finds is unknown as the process of defining this group is not yet complete.

In addition to pallasites, the class of mesosiderites includes iron-stony meteorites, and there are 349 recorded finds [Meteorite Bulletin Database, 2023]. Mesosiderites typically contain roughly equal amounts of silicate and metallic components, with a slight predominance of the former. Further classification of mesosiderites is based on the composition of the silicate part (groups A, B, and C) and the degree of metamorphism (petrologic types 0-4) [Powel, 1969; Floran, 1978; Kimura et al., 2020].

The Museum's meteorite collection includes seven samples from three different mesosiderites. The five specimens represent the Vaca Muerta meteorite (Chile), belonging to subgroup A1 (Fig. 3). Also in the research collection of the Museum, there are many small fragments of the same meteorite collected by the Museum in 2023. The collection also includes one specimen each of the mesosiderites NWA 8741 (classified as a representative of subgroup A4) and NWA 11761 (also from subgroup A4 but with an anomalous amount of troilite).

Fig. 3. Sample of the Vaca Muerta mesosiderite in the Museum's meteorite collection (FMM_10_232), gifted by A. Minakhin in 2023.

Iron Meteorites

The Museum's collections include 58 samples of iron meteorites, of which 36 are incorporated into the meteorite collection. Iron meteorites can be easily classified based on their nickel content, which determines their structure [Tschermak, 1883], distinguishable on the etched surface. Hexahedrites (H), containing up to 6 wt.% Ni, are almost entirely composed of kamacite, where taenite lamellae may align parallel to the cube faces (hexahedra). Hexahedrites are relatively rare, and in our collection, they are represented by only two meteorites (NWA11420 and Uakit).

Octahedrites (O) contain 6-14 wt.% Ni, resulting in a significant amount of taenite. Kamacite forms elongated structures within a taenite matrix. Octahedrites are further classified based on the width of kamacite structures (grain size) into giant, coarse, medium, and fine-grained categories [Buchwald, 1975]. Octahedrites are visually striking and are well-represented in the collection (29 samples from 17 meteorites). The aesthetically appealing specimens of the medium-grained octahedrite Muonionalusta (Fig. 4) are represented by five samples in our collection.

Ataxites (D) contain 14 to 66 wt.% Ni and mainly consist of taenite. They lack enough kamacite to create a Widmanstätten structure. In our collection, there are 6 samples from 4 meteorites (Chinga, Dronino, NWA859, and Gebel Kamil).

In addition to the structural classification for iron meteorites, a division into groups based on the ratio of gallium, germanium, and nickel has been

Fig. 4. Iron meteorite Muonionalusta, left - sample FMM_10_190, right - FMM_10_199.

proposed. It is assumed that meteorites from different groups belong to the cores of different celestial bodies [Goldberg et al., 1951; Wasson and Kimberlin, 1967]. This classification has undergone multiple revisions, and it is currently far from being finalized. As of today, there are 13 meteorite groups recognized [Krot et al., 2014] (1224 finds), with 151 iron meteorites (11%) not falling into any of the established groups. The meteorite collection (Table 2) includes samples from five out of the thirteen known groups: IAB – 13 specimens, IIAB – 5 specimens, IIG – 2 specimens, IIIAB – 2 specimens, IVA – 7 specimens. The collection currently lacks samples from groups IC, IIC, IID, IIE, IIF, IIIE, IIIF, IVB.

Iron meteorites classified outside recognized groups are represented by 7 samples from 4 meteorites. All these meteorites (Dronino, NWA859, Chinge, Gebel Kamil) belong to the ataxite group. In 2022, we registered a new iron meteorite, Orotukan, found in the Magadan region. Structurally, it belongs to the octahedrites, but based on the Ge, Ga, and Ni composition, it does not fall into any of the known groups. We plan to verify the results of the analysis, and only after that, transfer the type specimen to the main collection of the Museum. Therefore, at the moment, the material of the Orotukan meteorite (approximately 90 g), like other unregistered meteorites, is stored in the Museum's research collection. We also hope to obtain a more representative sample of this meteorite for the Museum's exhibition.

Impactites

Impactites are represented by 105 samples in the collection. The Popigai astrobleme (Yakutia) is characterized by 10 samples, including representative specimens of suevites and tagamites, as well as granite-gneisses and quartzites with traces of impact effects. In addition, meteorite craters in Russia are represented by three impactites from the Karla Crater (Chuvashia), three suevites from the Karskaya astrobleme (Nenets Autonomous Okrug), four impactites from the Jänisjärvi astrobleme (Karelia), and two impactites from the Kamensk crater (Rostov Oblast). Two impactites from the Elgygytgyn astrobleme (Chukotka) are recorded as coesite in the Museum's systematic collection.

Craters in other republics of the former USSR are represented by the allochthonous breccia of the Ternovka astrobleme (Dnipropetrovsk Oblast), the impactite of the Boltysh Crater (Kirovohrad Oblast), the impactite of the Chiyli Crater (Kazakhstan), two samples of zhamanshinite and lechatelierite (meteorite crater Zhamanshin, Kazakhstan).

Thanks to the active collections of A.A. Razumovsky, partly transferred in 2018-2019, the Museum has a good representation of meteorite craters in Western Europe. From Sweden, samples of tagamite and pseudotachylite from the Dellen crater, two impactites from the Mien crater, two samples of allochthonous breccia from the Mallingen crater, one representative of impact rocks from the Hummeln, Lockne, and Silijan craters were brought. The collection includes samples from three craters in Finland: suevite and tagamite from the Sääksjärvi crater, impactite from the Lappajärvi crater, and impactite from the Paasselkä crater. We also store four impactites from the Gardnos crater and the impactite from the Ritland crater (both in Norway), pseudotachylites, suevites, and allochthonous breccia from the Rochechouart crater (France), impactite from the Steinheim crater (Germany), suevite and allochthonous breccia from the Ries crater (Germany).

Impactites from the rest of the world are represented by samples from four astroblemes. The collection includes three samples of impactites from the Santa Fe crater (USA), one sample of impactites from the Vredefort crater (South Africa), impactite from the Agoudal crater (Morocco), and impactite from the Lonar crater (India).

Tektites are a type of impactites, often distinguished by their unique beauty. Discoveries of greenish transparent moldavites have been known since the 18th century, and they are often used in jewelry. These enigmatic glassy formations have been found on all

Table 2. Iron Meteorite Groups and Their Presence in the Samples of the Fersman Mineralogical Museum

	I	II	III	IV
A	El Taco (1), Odessa (1), Canyon Diablo (2), Campo Del Cielo (3), Morasko (1), Uruacu (1), Toluca (1), Mundrabilla (1), Maslyanino (1), Nantan (1)	NWA 11420(1), Uakit (1), Sikhote-Alin (2), Agoudal (1)	Wolfe Creek (1), Yarovoye (1)	Mounionalusta (5), Gibeon (2)
B				–
C	–	–	Reclassified into the IAB-sLM subgroup	
D		–	Reclassified into the IAB-sLH subgroup	
E		–	–	
F		–	–	
G		Twannberg (2)		

Notes: Column and row intersections correspond to groups of iron meteorites (IAB, IIAB, IIIAB, IVA, etc.). The cells list the meteorites of that group, and the number of available samples is indicated in parentheses. A dash indicates the absence of meteorites from that group in the Museum's collection. Cells in the table corresponding to non-existing groups are shaded in gray.

continents, and it's no wonder they occupy a worthy place in the Museum's collection. Moldavites are represented by seven samples (5 in the meteorite and impactite collection). Light-yellow Libyan glass is also represented by eight samples, some of which contain spherulites of cristobalite. The Museum's collection also includes tektites from Vietnam (1 sample), three indochinites from China, three indochinites from Thailand, seven fragments of quenched Darwin glass from Tasmania, three samples of philippinites (Philippines), tektite-like impact glass from the Aouelloul crater (Mauritania), irghizites from Kazakhstan, tektites from the Ilyinets meteorite crater (Vinnytsia Oblast), atacamites (Chile), and australites (Australia).

The collection of impactites includes samples of impactite-like rocks with a genesis not yet fully understood. Such samples include köfelsite (glassy siliceous rocks forming thin veins in gneisses) from the Koefels structure (Austria). Some researchers consider these rocks as mylonites [Mash et al., 1985], while others consider the Koefels structure a meteorite crater [Storzer et al., 1971].

Discussion

Representativeness of Meteorite Minerals

In the Museum's catalog of mineral species, there are 40 mineral species (including terrestrial analogs) out of 133 minerals discovered in meteoritic material. It can be said that the representation of the mineralogical collection in its meteoritic part is just over 30%. This is significantly less than for all mineral species in general (around 68% of mineral species are represented in the Museum's collection). Primarily, this is due to the insufficient study of the existing samples. It should be noted that the level of interaction between the Museum and researchers of meteoritic material has been insufficient for many years. Undoubtedly, museum samples contain more minerals than can be assumed from catalogs. As an example, well-studied samples of the meteorite NWA12590 [Konovalova et al., 2021a] can be mentioned, in which a number of meteorite-endemic minerals are described. The Museum holds a type specimen of this meteorite, and two more sections of this meteorite are recorded for the mineral species grossmanite and kushiroite, as well as one preparation passed by A.V. Kasatkin as tetrataenite. The transferred sections also contain hexamolybdenum and other rare intermetallics [Konovalova et al., 2021b], but it is not feasible to additionally separate individual samples or preparations for recording each discovered mineral species. Perhaps it is worth reconsidering the system of fixing new mineral species for the Museum in museum samples. This may be useful not only for significantly expanding the list of meteoritic minerals but also for describing unique mineralogical objects with a limited amount of material.

Representation of Meteorites in the Collection

In a relatively short period at the Fersman Mineralogical Museum, a sufficiently representative collection has been created, encompassing major types of meteorites. Ordinary and carbonaceous chondrites are well characterized (excluding very rare types). The collection includes representatives of all common types of iron and iron-stony meteorites. For relatively common meteorite groups, the Museum has managed to acquire good display samples. Rarer groups are represented by individual samples or are currently absent from the collection. Acapulcoites, enstatite chondrites, and aubrites in our collection are only conditionally present, as they are small fragments (about 1 mm in size) embedded in epoxy resin and recorded as samples of rare minerals. We see several ways for the development of the meteorite collection. Firstly, it is necessary to continue researching and registering new meteoritic material. Several years of such work have allowed the Museum to obtain rare carbonaceous chondrites and representatives of the ureilite and eucrite groups as registration masses. Material for research comes from many meteorite enthusiasts, but unfortunately, not all transferred samples turn out to be meteorites. Samples transferred for research are initially registered in the Museum's scientific research fund, preparations are made, and necessary analytical work is carried out. If the sample turns out to be a meteorite, its owner transfers to the Museum at least 20 g of material as a registration mass. After that, an application for registration is prepared, which is sent to the nomenclature committee of the International Meteorite Society, de facto serving as the international recorder of meteoritic material. During the review of the application, the committee may ask clarifying questions, answers to which sometimes require additional research. After approval by the committee, each meteorite is assigned a unique name, and its description is entered into the Meteorite Bulletin database. This allows preparing the registration mass of a new meteorite for consideration by the Museum's Expert Procurement Commission for its inclusion in the meteorite collection. The sections of a new meteorite are recorded in the Museum's thin section collection and are available for further study, including by external researchers. Rules for reviewing applications from research groups are outlined on the Museum's website (https://www.fmm.ru/Научно-исследовательский_фонд_образцов). If it is found that the sample submitted for research is not a meteorite, it is returned to the owner, and the research material remain in the scientific research collection. There may be cases when such a sample, not being a meteorite, is still of interest to the Museum. In this case, the sample owner is provided with the research results, and it is suggested to transfer this sample or its fragment to the Museum's collection. Secondly, permanent contacts with scientific groups, meteorite collectors, and dealers are necessary. This allows learning about new interesting finds and participating in their study, as well as acquiring good collection samples that can sometimes be obtained for the Museum as gifts or through exchanges. Thirdly, Museum staff may participate in meteorite expeditions. Organizing its own meteorite expeditions is currently beyond the Museum's capabilities, but the participation of individual employees in meteorite expeditions brings good results.

Representation of Impactites in the Collection

The collection includes impactites (105 samples) related to 27 out of 190 known meteorite craters. Among them, 19 impact structures are described on the territory of the Russian Federation, but the collection only includes representatives from six astroblemes. In most cases, these samples have not been further studied, and their catalog descriptions are based solely on macroscopic descriptions made by individuals who provided the samples. The modern petrographic classification scheme for impactites was adopted quite recently [Stoffler et al., 2007], and the entire existing collection requires careful scientific revision. Unfortunately, the Museum currently lacks specialists in impact material. It might be rational to involve external experts in studying the collection, but after the passing of V.I. Feldman (2011) and V.L. Masaitis (2019), their scientific groups disbanded, and finding a universal and professional researcher of impactites in Russia is extremely difficult. In addition to the revision and classification of the existing collection of impact rocks, a priority task is to authenticate some tektites (moldavites, indochinites, etc.), as there are counterfeits on the market due to their high value.

Exhibition of Meteorites and Impactites

In 2022, significant work began to update the exhibition at the Museum dedicated to the meteorite collection. For many years, the meteorite exhibition was maintained by A.Ya. Skripnik (Geochemistry Institute of RAS). The exhibition mainly consisted of unique samples from the meteorite collection of the Russian Academy of Sciences, formally transferred to the Museum's meteorite committee but physically remaining in the Museum. Employees of Geochemistry Institute of RAS (D.D. Badyukov, N.S. Bezaeva, K.A. Lorentz, K.M. Ryazantsev, and others) collaborated with Museum staff to revise the exhibition, update and illuminate showcases, update labels, add new exhibits, and clean old ones. Alongside this, Museum staff created a separate showcase (Exposition No. 126) featuring the best samples from the Museum's meteorite collection (87 samples). The next stage of the work is the creation of a comprehensive exhibition based on the updated concept for showcasing meteoritic and impact material. However, creating such a concept requires a multi-faceted balanced approach, and this work is not yet complete. The new exhibition needs to present the mineralogy of meteorites, the morphology of individuals, visually demonstrate textural features of structure, classification features, and much more. Displaying of impactites also requires a systemic, multi-faceted approach, and we hope to accomplish this work in the foreseeable future.

Acknowledgments

The authors thank K.A. Lorentz, V.V. Sharygin and I.V. Pekov for valuable comments that made it possible to improve the article.

References:

Плечов П.Ю., Белаковский Д.И., Паутов Л.А., Пеков И.В., Касаткин А.В., Агаханов А.А., Карпенко В.Ю., Некрылов Н.А., Гриценко Ю.Д., Гаранин В.К., Карпов А.О. Важнейшие научные результаты Минералогического музея им. А.Е. Ферсмана в 2019 году // Новые данные о минералах. 2020. №54(3). С. 74–95.

Berkley J.L., Taylor G.J., Keil K., Harlow G.E., Prinz M. The nature and origin of ureilites // Geochimica et Cosmochimica Acta. 1980. V. 4(10). P. 1579–1597.

Britvin S.N., Rudashevskii N.S., Krivovichev S.V., Burns P.C., and Polekhovsky Y.S. Allabogdanite, $(Fe,Ni)_2P$, a new mineral from the Onello meteorite: The occurrence and crystal structure // American Mineralogist. 2002. V. 87. P. 1245–1249.

Buchwald V.F. Handbook of iron meteorites. Their history, distribution, composition and structure. Arizona State University, 1975.

Chukanov N.V., Pekov I.V., Levitskaya L.A., Zadov A.E. Droninoite, $Ni_3Fe^{3+}Cl(OH)_8{\cdot}2H_2O$, a new hydrotalcite-group mineral species from the weathered Dronino meteorite. Geology of Ore Deposits. 2009. V. 51. P 767-773.

Eremeeva A.I. The Birth of Scientific Meteoritics (The History of Pallas's Iron). M.: Nauka, 1982. 253 p. (In Russian)

Floran R.J. Silicate petrography, classification, and origin of the mesosiderites: Review and new observations. In Proceedings of the Ninth Lunar and Planetary Science Conference, Houston, Texas, March 13–17, 1978. Pergamon Press.

Fuchs L.H. Djerfisherite, alkali copper–iron sulfide: a new mineral from enstatite chondrites // Science. 1966. V. 153. *P.* 166–167.

Goldberg E., Uchiyama A., & Brown H. The distribution of nickel, cobalt, gallium, palladium and gold in iron meteorites // Geochimica et Cosmochimica Acta. 1951. V. 2(1). P. 1–25.

Kallemeyn G.W., Rubin A.E., Wang D., & Wasson J.T. (1989). Ordinary chondrites: Bulk compositions, classification, lithophile-element fractionations and composition-petrographic type relationships // Geochimica et Cosmochimica Acta. 1989. V. 53(10). P. 2747–2767.

Kimura M., Sugiura N., Yamaguchi A., & Ichimura K. The most primitive mesosiderite Northwest Africa 1878, subgroup 0 // Meteoritics & Planetary Science. 2020. V. 55(5). P. 1116–1127.

Keil K. Enstatite achondrite meteorites (aubrites) and the histories of their asteroidal parent bodies // Geochemistry. 2010. V. 70(4). P. 295–317.

Konovalova K.A., Plechov P.Y., Litasov K.D., Shcherbakov V.D., & Vasiliev S.P. Evolution of Pyroxene Composition During CAI Formation in CV3-Chondrite Northwest Africa 12590. In 52nd Lunar and Planetary Science Conference. 2021a. No. 2548, p. 1517.

Konovalova K.A., Plechov P.Y., Litasov K.D., Shcherbakov V.D., & Vasiliev S.P. Mineralogy of the Complex Refractory Metal Nuggets in B1 Type CAI from CV3-Chondrite Northwest Africa 12590. In 52nd Lunar and Planetary Science Conference. 2021b. No. 2548, p. 1961.

Krivovichev V.G. Mineral species. St. Petersburg: St. Petersburg Publishing House. University, 2021. 600 p. (In Russian)

Krot A.N., Keil K., Scott E.R.D., Goodrich C.A., & Weisberg M.K. Classification of meteorites and their genetic relationships // Meteorites and cosmochemical processes. 2014. V. 1. P. 1–63.

McSween Jr H.Y. Petrographic variations among carbonaceous chondrites of the Vigarano type // Geochimica et Cosmochimica Acta. 1977. V. 41(12). P. 1777–1790.

McSween H.Y., Mittlefehldt D.W., Beck A.W., Mayne R.G., McCoy T.J. HED meteorites and their relationship to the geology of Vesta and the Dawn mission. The Dawn mission to minor planets 4 Vesta and 1 Ceres, 2012. P. 141–174.

Masch L., Wenk H.R., & Preuss E. Electron microscopy study of hyalomylonites – evidence for frictional melting in landslides // Tectonophysics. 1985. V. 115(1–2). P. 31–160.

Meteorite Bulletin Database. 2023. Online resource, https://www.lpi.usra.edu/meteor/metbull.php

Metzler K., Hezel D.C., Barosch J., Wölfer E., Schneider J.M., Hellmann J.L., Berndt J., Stracke A., Gattacceca J., Greenwood R.C., Franchi I.A., Burkhardt C., Kleine T. The Loongana (CL) group of carbonaceous chondrites // Geochimica et Cosmochimica Acta. 2021. V. 304. P. 1–31.

Mittlefehldt D.W., Lindstrom M.M. Geochemistry and genesis of the angrites // Geochimica et Cosmochimica Acta. 1990. V. 54(11). P. 3209–3218.

Nazarov M.A. Meteorite collection of the Russian Academy of Sciences // Museums of the Russian Academy of Sciences. Almanac. 1999. M.: Nauchniy Mir, 2000. p. 47–62. (In Russian)

Pekov I.V., Perchiazzi N., Merlino S., Kalachev V.N., Merlini M., Zadov A.E. Chukanovite, $Fe_2(CO_3)(OH)_2$, a new mineral from the weathered iron meteorite Dronino // European Journal of Mineralogy. 2007. V. 19. P. 891–898.

Pekov I.V., Zubkova N.V., Agakhanov A.A., Turchkova A.G., Zhitova E.S., Pushcharovskii D.Y. A New Chladniite Variety from Volcanic Exhalations. The Genetic Crystal Chemistry of Chladniite. Doklady Earth Sciences. 2023. V. 512. №2. P. 975-982.

Plechov P.Yu., Belakovsky D.I., Pautov L.A., Pekov I.V., Kasatkin A. V., Agakhanov A. A., Karpenko V. Yu., Nekrylov N.A., Gritsenko Yu.D., Garanin V.K., Karpov A.O. The most important scientific results of the Fersman Mineralogical Museum in 2019. New Data on Minerals. 2020. 54(3), 74–95. (In Russian)

Powel B.N. Petrology and chemistry of mesosiderites – I. Textures and composition of nickel-iron // Geochimica et Cosmochimica Acta. 1969. V. 33(7). P. 789–810.

Rubin A., Ma C. Meteorite Mineralogy. Oxford Research

Encyclopedia of Planetary Science, 2020. 49 p.

Storzer D., Horn P., & Kleinmann B. The age and the origin of Köfels structure, Austria // Earth and Planetary Science Letters. 1971. V. 12(2). P. 238–244.

Stöffler D. and Grieve R.A.F. Impactites, Chapter 2.11 in Fettes D., and Desmons J. (eds.) Metamorphic Rocks: A Classification and Glossary of Terms, Recommendations of the International Union of Geological Sciences, Cambridge University Press, Cambridge, UK, 2007. P. 82–92, 111–125, and 126–242.

Tschermak G. Beitrag zur classification der Meteoriten. Sitzber. Akad. Wiss. Wien, Math.-Naturwiss. Kl., Abt. I. 1883. B. 88. S. 347–371.

Van Schmus W.R., & Wood J.A. A chemical-petrologic classification for the chondritic meteorites // Geochimica et Cosmochimica Acta. 1967. V. 31(5). P. 747–765.

Wasson J.T., & Kimbeblin J. The chemical classification of iron meteorites – II. Irons and pallasites with germanium concentrations between 8 and 100 ppm // Geochimica et Cosmochimica Acta. 1967. V. 31(10). P. 2065–2093.