Teacher’s Manual

Chapter 6: Meteorites

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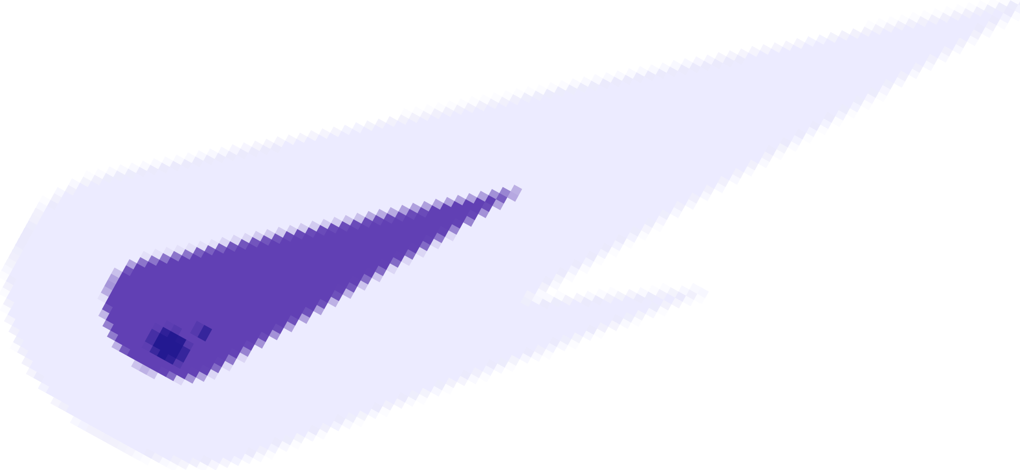
Work Package 3
StAnD Academy



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6.1 Meteorites

A meteorite is a piece of solid matter from space that survives its journey through the Earth's atmosphere and lands on the surface.

Meteorites come from asteroids, comets, or other planetary bodies. When the piece of solid matter causing the meteor makes it to the ground, it is called a meteorite.

Artist's impression of a meteorite impacting a planetary surface, creating a bright flash and ejecting material into the air.

6.1.1 Formation of Planetary Bodies

6.1.1.1 Planetary Formation

Process: The processes of planetary formation began at the birth of our solar system. Gas and dust particles collided to form grains, which then became pebbles, and eventually larger bodies called planetesimals.

Role of Jupiter: The formation of Jupiter, the largest planet, halted the accretion process in the region between Mars and Jupiter, creating the main belt of asteroids.

Significance: The asteroid belt preserves a record of the early stages of planetary formation, which helps scientists understand the processes that led to the formation of terrestrial planets like Earth, Mars, Mercury, and Venus.

An artist's depiction of the early solar system, showing the formation of planetesimals from gas and dust.

6.1.2 Differentiation and Composition of Planetesimals

6.1.2.1 Differentiation

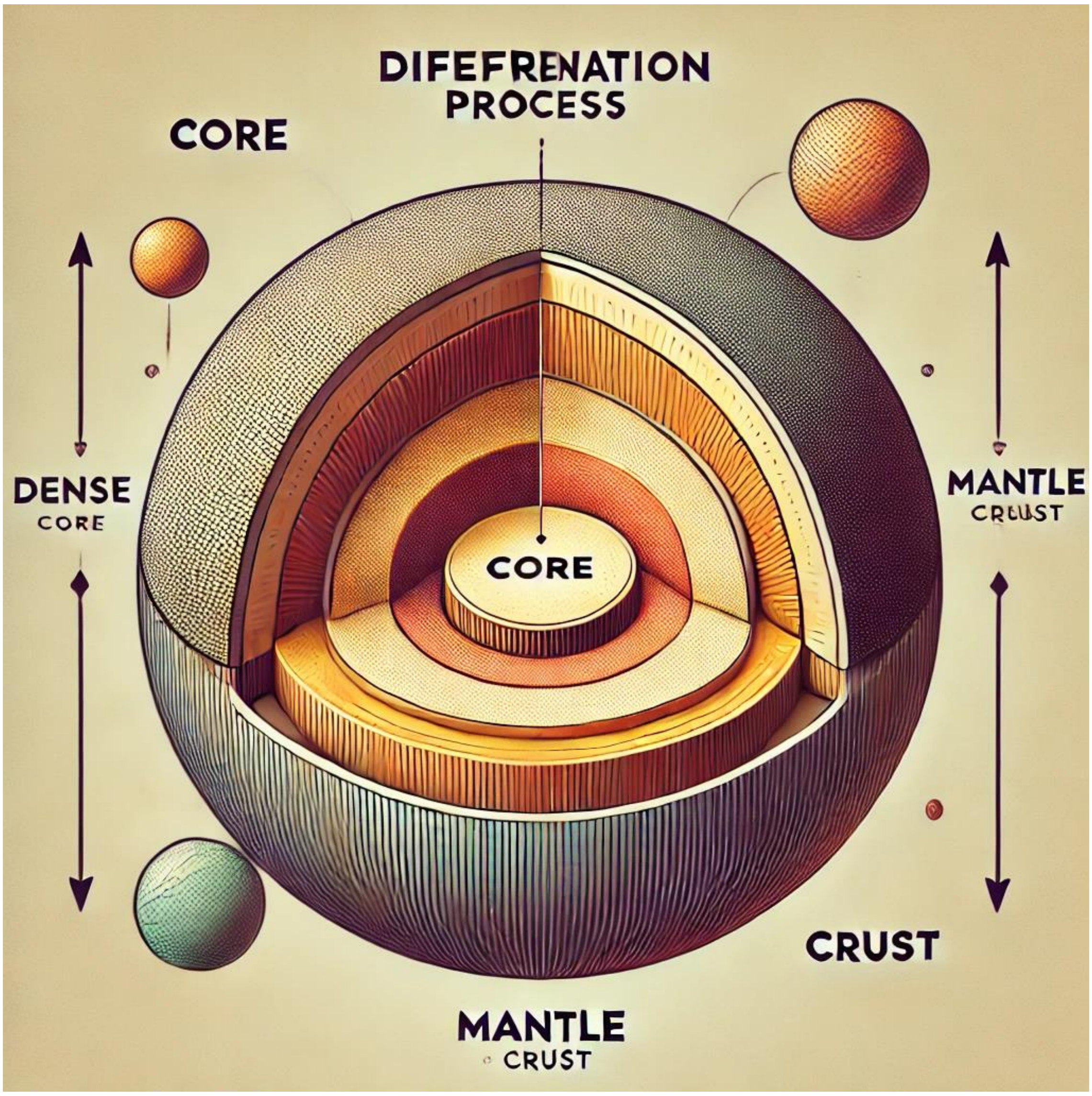
Process: Differentiation is the process where denser materials like metallic iron and nickel sink to form a core, while lighter silicate materials float above to form a mantle and crust.

Implications: This process varies in completeness depending on the size of the body. Larger bodies like Earth, Mars, and the Moon have fully differentiated, while smaller bodies may not have completed the process.

6.1.2.2 Study of Differentiation

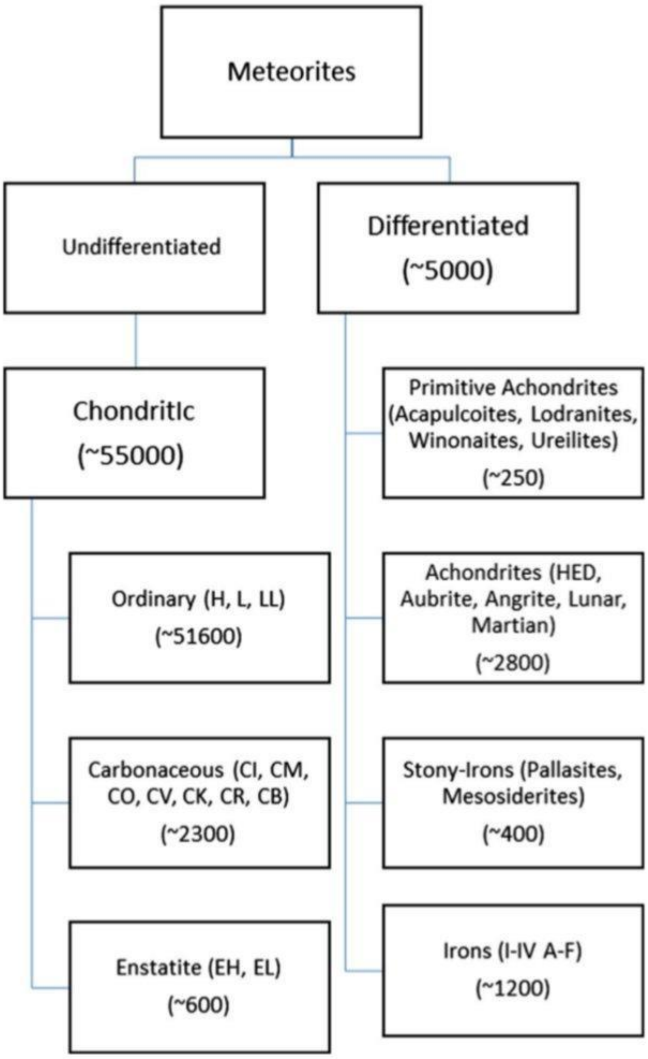
Scientists investigate what planets are made of and how they formed and evolved. This helps in understanding why planets like Earth, Mars, Mercury, and Venus turned out so differently.

Methods are based on observations through telescopes, space missions, and analysis of meteorites.



A diagram illustrating the differentiation process, with denser materials forming a core and lighter materials forming a mantle and crust.

6.2. Classification of Meteorites

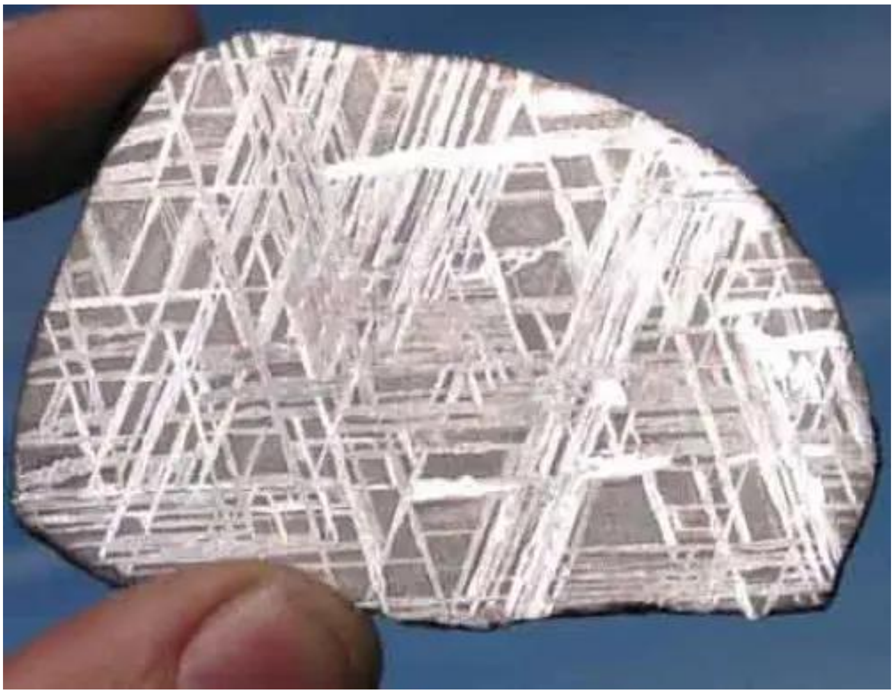


Meteorite classification that divides meteorites based on whether their parent bodies experienced igneous differentiation or not. Numbers indicate how many classified meteorites are known in each group. Figure reproduced from [McCoy, 2021].

6.2.1 Types of Meteorites

6.2.1.1 Iron Meteorites

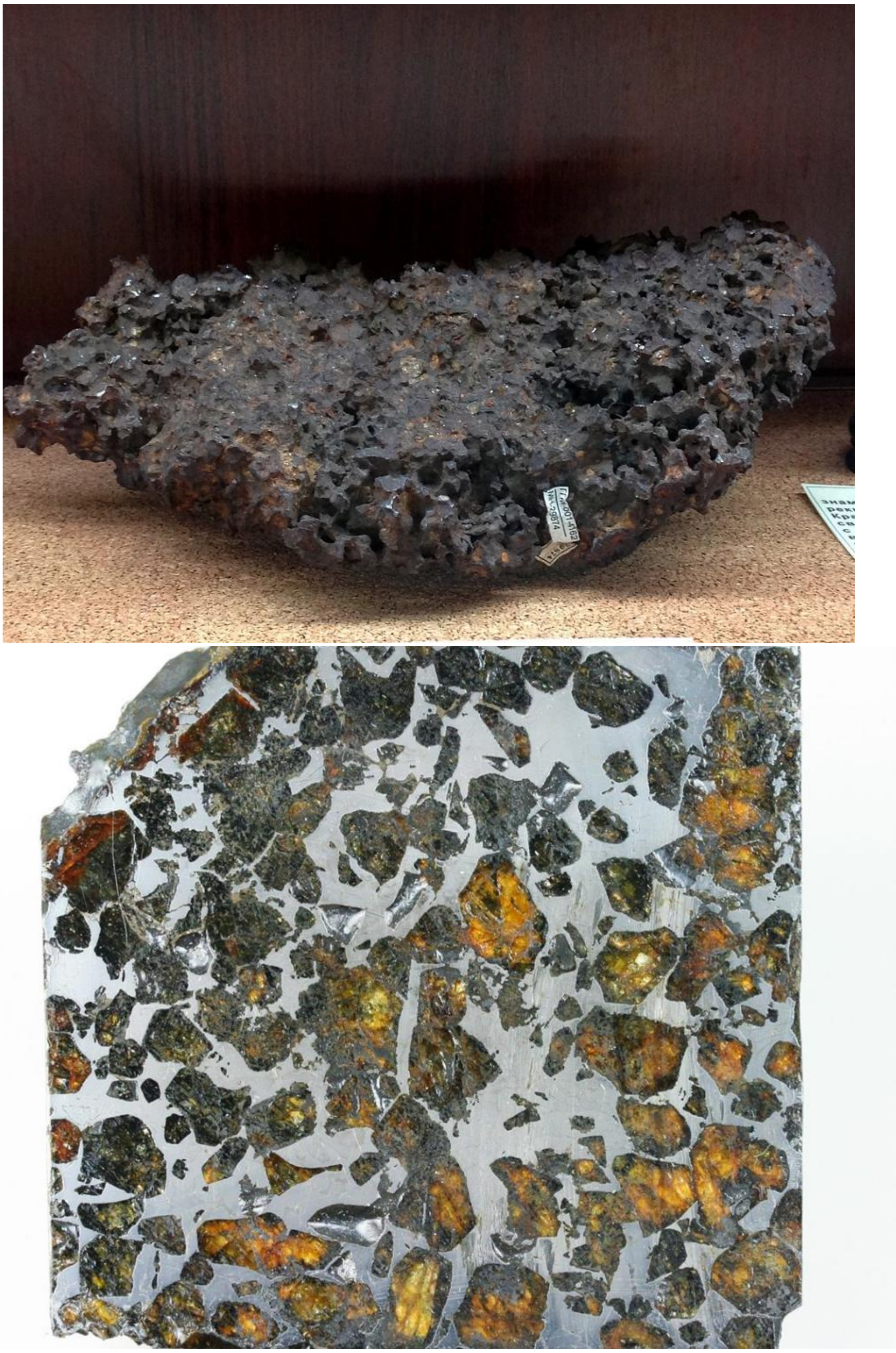
Mainly composed of iron nickel metal with small amounts of sulphide and carbide minerals. Exhibit a distinctive crystalline structure known as Widmanstätten texture, which forms bands of varying nickel content. Thought to be the cores of asteroids that melted early in their history. They provide insights into how the metallic cores of planets formed.



A polished iron meteorite, showing its distinctive Widmanstätten patterns, Meteorite from an unknown source (www.arizonaskiesmeteorites.com).

6.2.1.2 Stony Iron Meteorites

Pallasites: Contain olivine crystals (a form of magnesium iron silicate) embedded in metal. May have formed at core mantle boundaries or through impact melting. Offer insights into the formation of Earth's and other terrestrial planets' core mantle boundaries.



The first image is Anomalous PMG Pallasite meteorite from Krasnoyarsk meteorite, Novosyolovsky District, Krasnoyarsk Krai, Russia, the second PMG pallasite meteorite from Seymchan meteorite, Srednekansky District, Magadan Oblast, Russia (www.mindat.org)

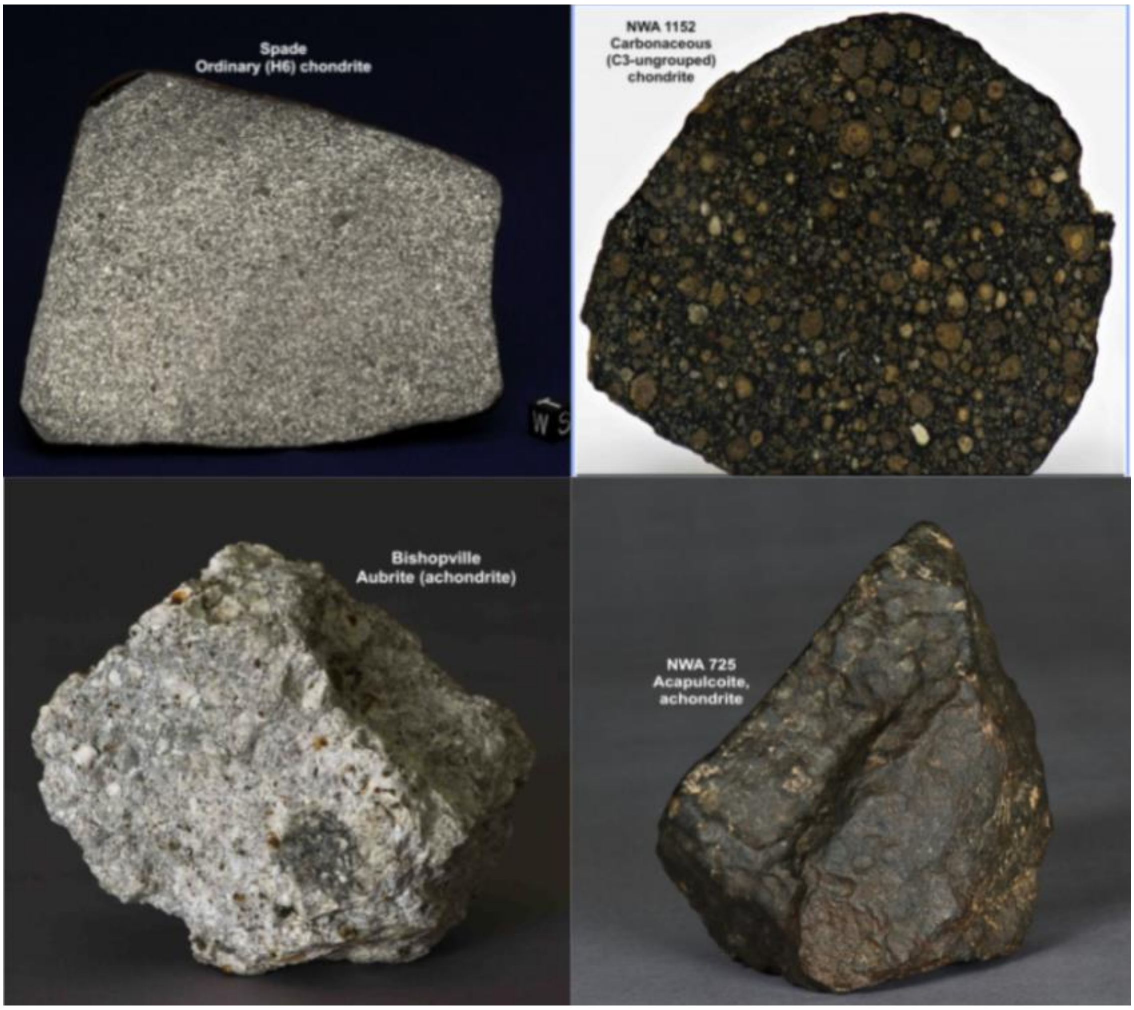
Meso Siderites: Formed after collisions between asteroids, resulting in a mix of metal and silicate fragments. Molten metal mixed with solid fragments of silicate rocks during asteroid collisions. Record the history of meteorites and conditions required for asteroids to melt and form iron cores.

Mesosiderite A1 meteorite from Vaca Muerta meteorite, Taltal, Antofagasta Province, Antofagasta, Chile (www.mindat.org)

6.2.1.3 Stony Meteorites

Chondrites: Over 4.5 billion years old, making them some of the most primitive and pristine rocks in the solar system. Made from droplets of silicate minerals mixed with small grains of sulphides and iron nickel metal. They have a distinctive appearance with millimetre sized granules called chondrules. Represent the material from which the solar system formed and have remained relatively unchanged compared to rocks from larger planets.

Achondrites: Originate from planetesimals that have undergone internal melting, forming a core, mantle, and crust. Include meteorites from asteroids, Mars, and the Moon. Achondrites are igneous, meaning they were once melted and then crystallized. Provide insights into the internal structure and formation of planets, including Earth, rarely found.



a) ordinary chondrite (Arizona State University, Meteorite Studies-ASU/CMS) b) northwest Africa meteorites; R chondrite (mindat.org) c) Bishopville; aubrite meteorite, Sumter County, South Carolina, fall on March 25, 1843 (ASU/CMS) d) Northwest Africa 725; acapulcoite achondrite, Morocco (ASU/CMS).

6.2.1.3 Specific Meteorites and Their Origins

HED Meteorites (Howardite-Eucrite-Diogenite): Linked to asteroid Vesta, which shows evidence of complete differentiation. Vesta is the second largest asteroid in the asteroid belt and the only large asteroid that shows evidence for complete differentiation. Vesta has large craters on its south pole, indicating significant material has been launched off, forming HED meteorites. Vesta's craters indicate that significant material has been launched off, forming meteorites that help us understand planetary differentiation and composition.

Image of asteroid Vesta, taken by NASA's Dawn spacecraft on July 9, 2011(NASA/JPL-Caltech/UCLA/MPS/DLR/IDA). Bununu howardite meteorite from the asteroid Vesta, found in 1942 (Hap McSween (Universität Tennessee) und Andrew Beck/Tim McCoy (Smithsonian Institution)).

6.2 Micrometeorites

6.2.1 What are Micrometeorites?

A micrometeorite is a rock particle of interplanetary origin, the size of a grain of dust or sand, which has passed through the earth's atmosphere and reached the earth's surface. Through friction with molecules in the Earth's atmosphere, it was heated and slightly to very strongly chemically and mineralogically altered.

Glass Cryptocrystalline Barred Olivine Porphyritic

Different types of micrometeorites (https://www.micrometeorites.org/galerie)

This is to be distinguished from:

- Fragments of larger meteorites in the size of a few millimeters - called mini meteorites
- tiny rock spherules that are formed when particles from larger meteorites detach when they pass through the Earth's atmosphere, melt and then fall to Earth as cooled spherules - called “*ablation spherules*” or meteoritic burn-up
- small rock particles that impact on the surfaces of satellites or other artificial spacecraft in orbit around the Earth - also often called micrometeorites
- tiny rock particles of interplanetary origin that drift in the air stream in the stratosphere (at an altitude of approx. 20-25 km) and are captured experimentally using aircraft - usually referred to as IDPs (Interplanetary *Dust Particles*), but sometimes also called micrometeorites
- small rock particles of interplanetary origin that have fallen on other planets or moons - also called micrometeorites

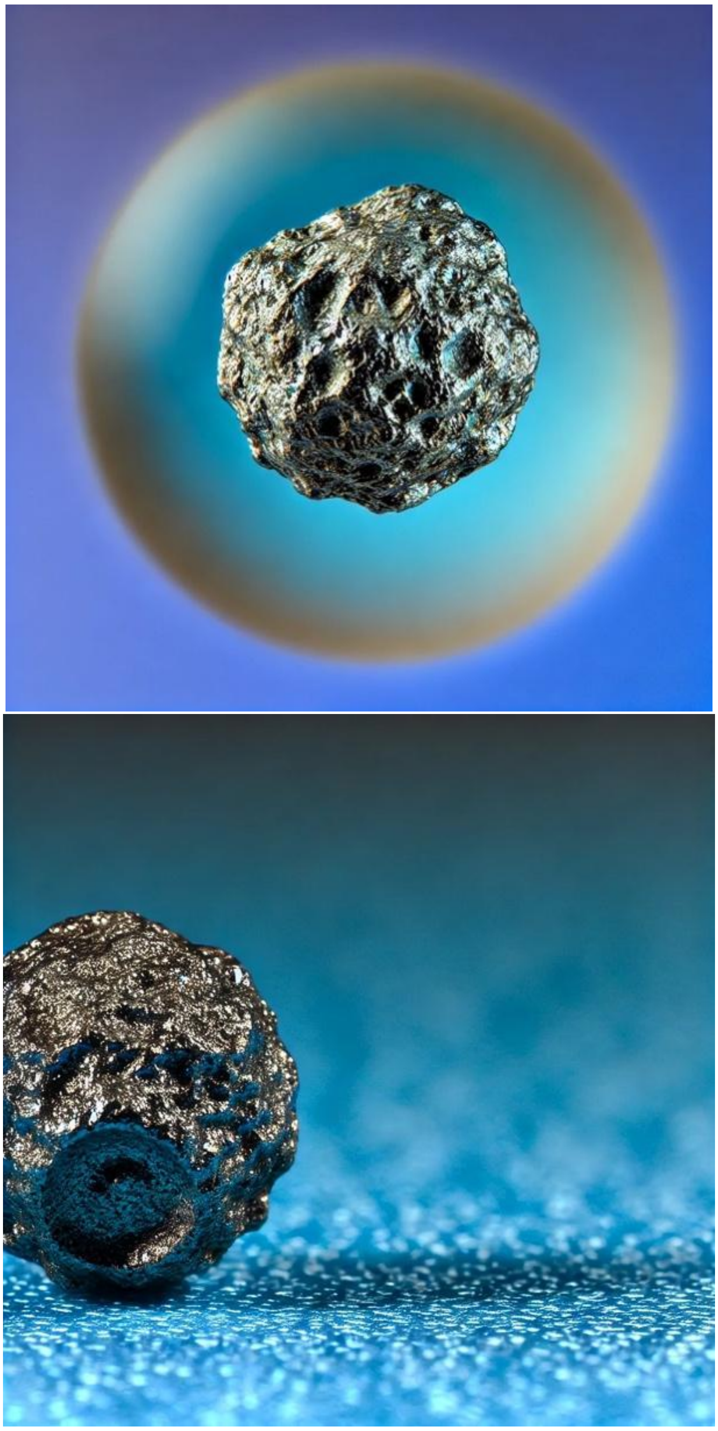
6.2.2 How are micrometeorites formed?

A micrometeorite has its origin in an interplanetary (cosmic) rock particle of a few micrometers to a few millimeters in size.

These small rock particles are formed during collisions of asteroids or meteoroids, mainly in the asteroid belt and through evaporation from comets as they approach the sun, and possibly also through ejection during asteroid and comet impacts into other planets and moons. It is also conceivable that some tiny particles are of interstellar origin.

The reservoir of cosmic dust near the Earth's orbit around the sun is constantly changing - viewed in geological time periods: Particles larger than approx. 1 µm spiral towards the sun through gravitational attraction or the so-called P-R drag (Poynting-Robertson drag) and can then encounter a planetary or lunar orbit when they cross it. For particles smaller than approx. 1 µm, on the other hand, solar radiation pressure prevails, which is why they are propelled into the outer regions of the solar system. Both constant emptying processes of the dust reservoir are countered by filling through new collisions or comet outgassing.

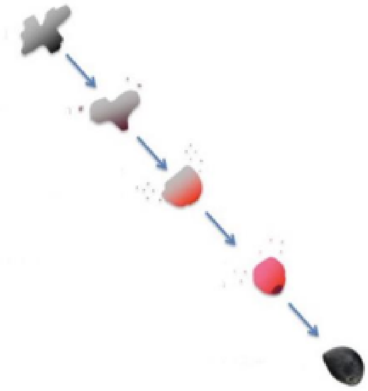
Due to the high speed of the dust particles in interplanetary space (relative speeds to the Earth usually between approx. 11 and 72 km/s), they heat up rapidly when they enter the Earth's atmosphere at an altitude of approx. 70-100 km due to the interaction with air molecules and are slowed down within seconds. Parts can be blown off or melted or entire particles can be blown apart. Particles a few millimeters in size can be observed indirectly at night under a clear sky as “shooting stars”. Smaller dust grains, which often do not burn up completely and then fall to earth as micrometeorites, do not produce any visible luminous phenomena, but can also be registered with high-performance radar telescopes.



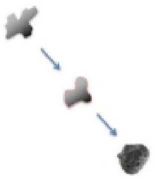
AI generated micrometeorite images

The heating leads to chemical-mineralogical changes in the particle. Depending on the temperature level and the duration of exposure to high temperatures, this ranges from heating or melting of the particle surface to complete melting of the particle. In the latter case, the melt recrystallizes during the subsequent rapid cooling. Such micrometeorites then usually have an approximately round shape and are therefore also referred to as cosmic spherules. Most micrometeorites found in urban areas to date are such “cosmic spherules”.

a) **Formation of Cosmic Spherules**
1. Original Form in Space
2. Heating and Flaking of Parts
3. Partial Melting and Evaporation of Volatile Elements
4. Complete Melting, Evaporation of Additional Elements, Separation of Melt
5. Cooling and Recrystallization



b) **Formation of Partially/Unmelted Micrometeorites**
1.Original Form in Space
2.Peripheral Melting/Heating
3.Cooling



The degree of heating of the interplanetary dust grain increases

- with its speed when it enters the Earth's atmosphere
- with its mass and density
- the steeper its angle of entry

The deceleration of the particle due to the collision with air molecules and the process of melting and recrystallization takes place within a few seconds. It then falls to the earth's surface at “falling speed” as a micrometeorite or, if the mass is low, remains in higher layers of air for some time beforehand.

6.2.3 How common are micrometeorites?

Estimates and calculations of the total mass of micrometeorites that fall to earth every year today are between 1500 and 5000 tons. If we continue with 1500 tons and assume an average weight of a micrometeorite of around 5 µg, this results in a figure of around 300 trillion micrometeorites hitting the earth each year or, to put it another way, an average of 1 micrometeorite per year per almost 2 m² of surface area. These values can serve as a rough guide.

Basically, there are large quantities of micrometeorites "everywhere" on Earth. Their total mass exceeds that of meteorites many times over. Nevertheless, perhaps only a few teaspoons of micrometeorite material have been collected on Earth to date. The difficulty lies in extracting them from the surrounding terrestrial dust.

It is known from analyses of sediments that the influx of micrometeorites has not been uniform throughout the Earth's history. And there is the assumption that in the very early history of the earth, at the time of the *Late Heavy Bombardment (historical influx of meteorites)*, around 600 million years after the formation of the earth, not only were meteorite impacts many times more frequent than today, but also the quantity of micrometeorites falling to earth. These may have made a substantial contribution to the accumulation of water on Earth.

6.2.4 How can you recognize a micrometeorite?

The appearance of micrometeorites varies greatly due to the different compositions of the original particles, the very different chemical change processes of these as they pass through the Earth's atmosphere, but also due to their different sizes and rotational behavior and, last but not least, due to the different lengths of time on Earth during which they are exposed to weathering processes.

A distinction can be made between non-melted micrometeorites and melted and subsequently recrystallized micrometeorites (spherules), whereby there are transitional forms. The former can be fragile, porous structures but also more compact, solid ones. The latter are generally stable and at best partially porous structures. The former often show a change in the surface caused by the heat on entering the earth's atmosphere, which is most clearly visible in the cross-section. The latter exhibit characteristic crystallization forms, which in turn depend on the chemical composition and the temperatures reached or the period of recrystallization. The variation of the recrystallized spherules ranges in the more common types from glassy to microcrystalline structure, to banded crystalline to porphyritic (large crystals in a fine crystalline or glassy matrix). There are compact and porous forms. Occasionally drops containing iron and nickel are found on the outer edge of a spherule. Most micrometeorites are dark gray to black, but some are green, brown or white. How to recognize most of the micrometeorites is described here(in the second part).

Although there are a number of characteristics by which micrometeorites can be identified as such, their overall appearance is quite similar to that of man-made dust particles, which outnumber them almost everywhere. The latter are produced by a variety of industrial processes, e.g. by flexing, welding or other construction work with metal or rock, or as remnants of fireworks. Some natural processes can also produce similar particles - but they only play a significant role in terms of quantity locally (in terms of time or space).

6.2.5 Where can micrometeorites be found?

In principle, micrometeorites fall to Earth largely randomly and therefore uniformly. The fact that sampling for scientific research into micrometeorites has so far concentrated on individual selected areas is because man-made dust is greatly reduced there or does not occur at all. The latter applies to ice layers or sediments with deposits from pre-industrial times. In regions far from human civilization (e.g. Antarctica, Greenland, Atacama), man-made dust on the earth's surface is greatly reduced, at least in terms of quantity.

For a long time, finding micrometeorites in areas inhabited by humans was considered a Sisyphean task or even impossible. It was only a few years ago that the Norwegian jazz musician Jon Larsen, together with the geologist Matthew Genge from Imperial College London, showed that this is possible. Not least thanks to the Norwegian's pioneering work and documentation, the number of successful urban micrometeorite collectors is increasing rapidly worldwide. A description of suitable locations for the search can be found (see section 6.2.7).

6.2.6 Classification of micrometeorites

The prevailing classification of micrometeorites (Genge et al. 2008, also Folco & Cordier 2015, supplemented by Suttle & Folco 2020) was established based on comparative observations of several thousand polished particles, partly supported by quantitative analyses of the elements or mineral phases.

It is mainly based on differences in the structure of the bodies, on different chemical compositions and on morphological differences due to the degree of heating or melting of the particles as they pass through the Earth's atmosphere.

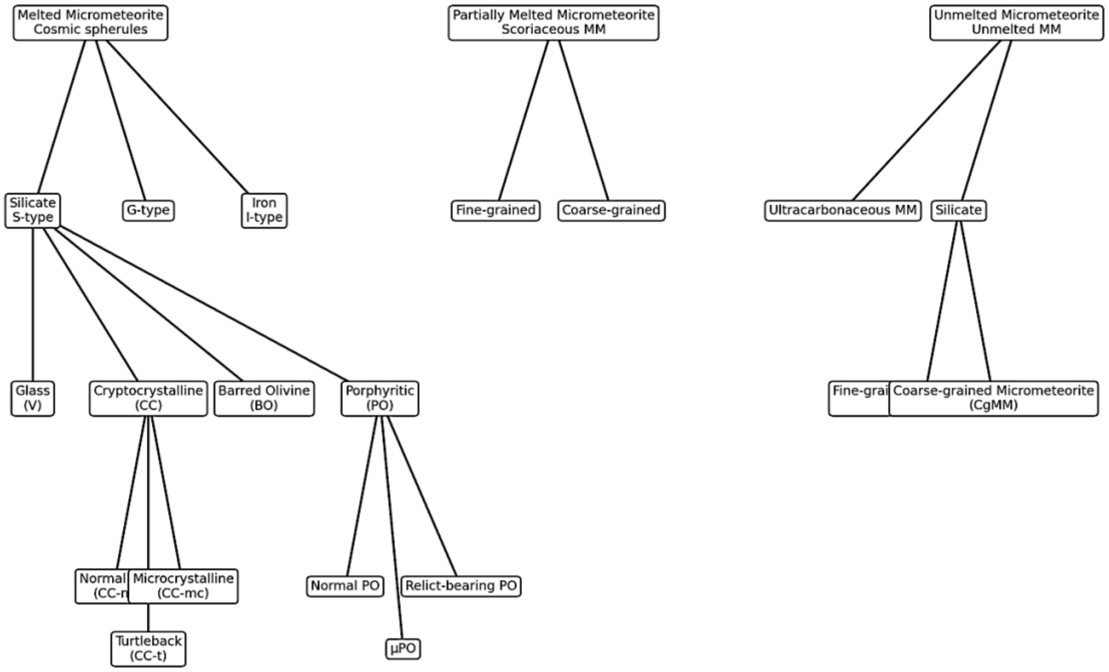
All these characteristics are characterized by numerous transitions (because the underlying processes are gradual), so that a clear classification cannot always be made. Nevertheless, the classification is a valuable aid in technical communication about micrometeorites. It can also help to better understand the different genesis of micrometeorites and their different origins.

6.2.6.1 Classification based on surface features

Classification based solely on the surface characteristics of an urban (less weathered) micrometeorite is often possible in principle, but involves additional uncertainties and inaccuracies, as information about the interior of the particle is not included. For example, after polishing 48 urban micrometeorites, Suttle et al. (2021) classified 12.5 % of them differently compared to the previous classification based on surface analyses.

The classification system and the different types

The following diagram shows the classification system of micrometeorites. Types in dashed boxes usually require an insight into the interior of the particle and thus the preparation of a section for classification. A classification is generally made down to the lowest level, which can still be made purely based on surface features.



Micrometeorite Classification after Genge et al. (2008)

At the highest level of classification, a distinction is made between three groups

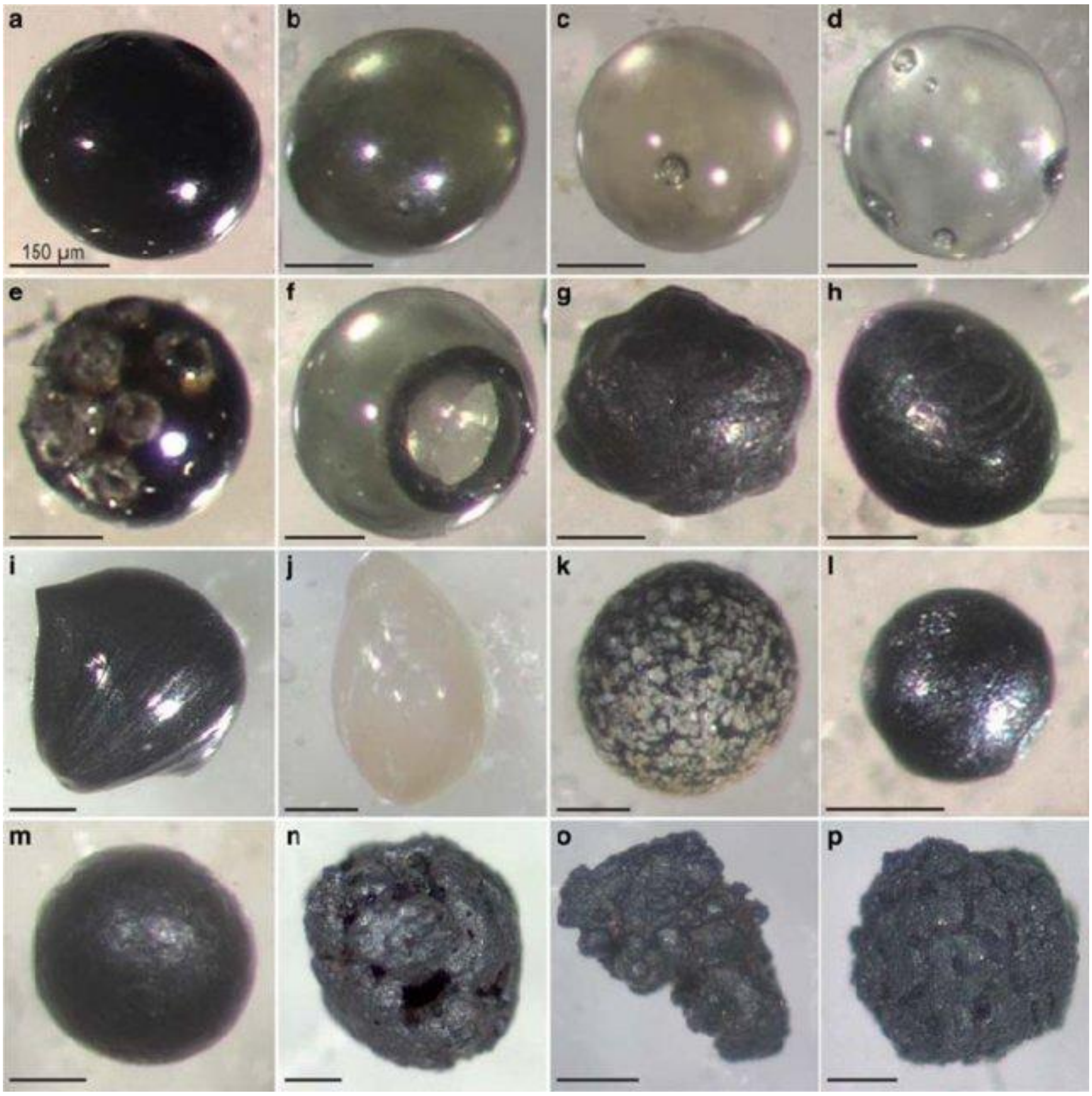
- *Unmelted micrometeorites (unmelted micrometeorites*)
- *Partially melted* **micrometeorites** (*partially melted / scoriaceous micrometeorites*)
- Melted **micrometeorites** (*melted micrometeorites / cosmic spherules*)

Depending on the group, different criteria are used for further subdivision. The exact classification of the levels and their naming (class, type, subtype, variant) is omitted here, as both vary in the literature and are not relevant in practice. To simplify matters, the term type is always used.

In the case of **unmelted micrometeorites**, the original structure of the original body has been preserved. A distinction is made as to whether it is fine-grained (*FgMM*) or coarse-grained (*CgMM*) or whether it has a high proportion of volatile elements (*ultracarbonaceous MM*). In the case of significant marginal heating, a “fire rim” (*igneous rim*, *magnetite rim*) can occur or be completely absent.

Fine-grained micrometeorites (*FgMM*) consist of microscopically small mineral grains similar to the matrices of CI, CM and CR meteorites. They are often dominated by amorphous, mostly iron-rich silicates, can be thermally altered or unaltered, compact or porous and chemically homogeneous or heterogeneous.

Coarse-grained micrometeorites (*CgMM*) have magmatic textures and are dominated by olivines/pyroxenes (commonly found in meteorites and on the surfaces of other planetary bodies) several micrometers in size, often within a glassy groundmass with accessory metal sulphides and iron oxides. A *CgMM* can also consist of a single crystal.



Stereomicroscopic images of various classes of micrometeorites. The types are defined in Table 1. (a–f) Glass cosmic spherules showing the most common range of colours and variable vesicularity. (g) Cryptocrystalline cosmic spherule with characteristic turtle-back (polyhedral-like) morphology. (h–i) Barred olivine cosmic spherules showing characteristic striations. (j) CAT cosmic spherule with its characteristic milky white colour. (k) Porphyritic cosmic spherule. (l) I-type cosmic spherule with its characteristic metallic lustre. (m) G-type cosmic spherule. (n) Partially melted micrometeorite with characteristic scoriaceous structure. (o–p) Unmelted micrometeorites with characteristic angular to sub-angular shapes. Scale bars ¼ 150 mm. All micrometeorites are from the Transantarctic Mountain collection. (Folco&Cordier 2015)

Carbonaceous micrometeorites (*ultracarbonaceous MMs*) consist of a network of amorphous carbon, olivine ($(Mg,Fe)_2SiO_4$), pyroxene and other minerals. Only a few specimens have been found so far, all in Antarctic ice. Comets are attributed to them as the most likely source.

The **partially melted micrometeorites** can only be classified as fine- or coarse-grained based on the relict phases. Characteristic and name-giving for this type, also known as *scoriaceous* (“slag-like”), are the numerous pores inside the body, which, however, are only recognizable in their multitude in cross-section. Under the microscope, these particles often have a lobed surface structure and sometimes a faint yellowish-brass color in the otherwise rather dull grayish body, which could be due to the iron sulphide droplets that are often present on the surface.

In the (almost) **completely melted micrometeorites** (**cosmic spherules**), the original material of the grains has melted and mixed. The primary phases are therefore no longer recognizable and a significant part of the information of the original body has been lost. Here the subdivision is based on the still recognizable different overall chemical composition of the original material (silicate, iron, mixed form) and within the silicate (*S-type*) also on morphological differences due to different rates of recrystallization.

The degree of melting and the speed of recrystallization is largely dependent on the size of the particle, its density, speed on entry into the earth's atmosphere and the angle of entry. This is reflected in the size distribution of melted and unmelted micrometeorites: Unmelted micrometeorites predominate for particle sizes < 50 µm, for micrometeorites > 100 µm (usually the size of micrometeorites recovered from urban areas) they only play a subordinate role.

A distinction is made between **cosmic spherules** according to the source material:

- Silicate (***S-type***)
- Iron-dominated (***I-type***)
- Intermediate form (***G-type***)

Silicate cosmic spherules (*S-type*) dominate in the collections with > 95 %. Representatives of *I-type* and *G-type* usually make up about 1-2 % each of the spherules. In urban collections, however, they are often even rarer or completely absent due to the difficulty of distinguishing them from industrial spherules.

In the case of silicate cosmic spherules, two immiscible melts formed during heating, the dominant silicate and the metallic one. Due to the higher density, the metallic melt migrates to the edge of the particle and can separate completely from the silicate melt or recrystallize at the edge and finally appear as a*metal bead*,*metal droplet* or as a tiny µm-sized droplet with planting group elements (*PGE nuggets*).

As the melting process begins at the outer edges of the particle due to friction with the air molecules, individual relict minerals (mainly Mg-rich olivines, less frequently pyroxenes, chromites and feldspars) can be spared from complete melting in the interior and ultimately remain as such in the restarting body. This can be observed above all in the *Porphyritic* type, but only after a section has been made. In the *Scoriaceous* type, such relict minerals occur even more frequently. The vast majority, however, consists of newly formed crystals from the melt, whose structure depends largely on the rate of recrystallization: The higher this, the smaller the crystals, with the glassy micrometeorites without recognizable crystals at the fastest end and porphyritic micrometeorites with large crystals at the slowest end.

S-type spherules are therefore also divided into the following types depending on the predominant cooling processes:

- **Glass** (V) = Vitreous
- **Cryptocrystalline** (CC)
- **Barred Olivine** (BO)
- **Porphyritic** (PO)

The **CAT spherules** and **Ca-Al spherules**, which are characterized by a higher degree of evaporation of the material, whereby the refractory elements (Ca, Al, Ti) are relatively enriched, are sometimes separated from this by special chemical composition.

Suttle & Folco (2020) have introduced a refined classification of **cryptocrystalline micrometeorites**, which is adopted here. It is easy to understand based on surface features.

- **Microcrystalline** (CC-mc): in places with predominant lattice structure of the crystals (typical for BO), in places with randomly oriented olivine and magnetite crystals (typical for CC)
- **CC-turtleback** (CC-t): with several elevated crystalline areas whose edges are recessed, giving the spherule a turtle-shell-like surface structure - produced by crystal growth that began on the surface and continued into the interior of the spherule. Mostly without recognizable magnetite crystals.
- **CC-normal** (CC-n): with olivine and magnetite dendrites in submicrometer size without signs of bar structures.

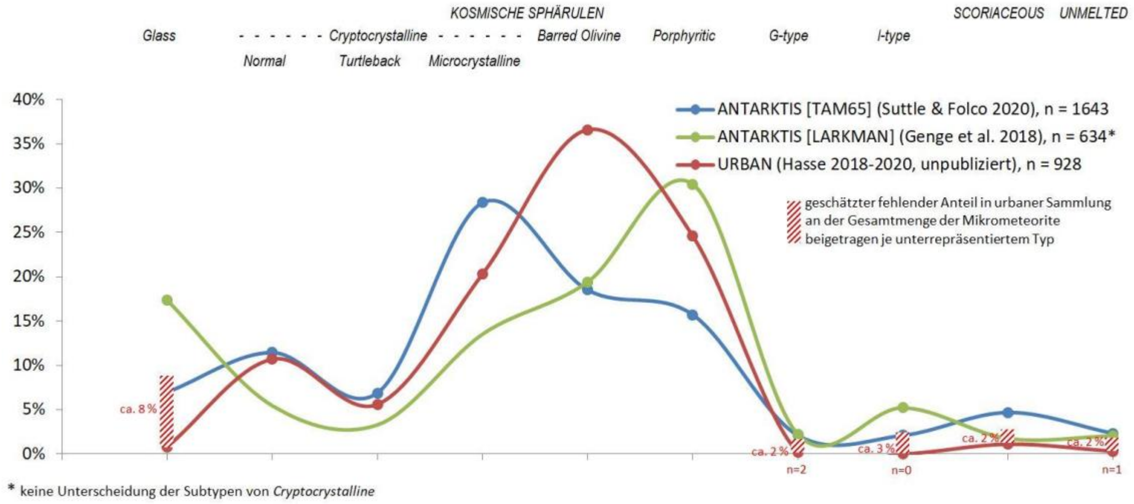
Suttle & Folco (2020), adopted by Ginneken et al. (2017), also describe a further subdivision into “normal” PO and µPO for the **porphyritic** type. Normal PO show “euhedral” crystals, i.e. large (> 10 µm) crystals with clearly defined crystal faces. Representatives of µPO show numerous “subhedral” (only partially equipped with clear crystal faces) smaller (< 10 µm) crystals and often numerous air bubbles. Differentiation in general is only possible based on polished samples and is therefore not adopted here.

Genge et al. (2008) recommend labelling porphyritic olivines that still contain unmelted relict minerals with the prefix “*relict-bearing*”. This can also only be proven based on sections.

6.2.6.2 How common are which types?

Micrometeorite collections from the Antarctic have the advantage that they are quite representative in terms of types, because most micrometeorites there can be extracted from the sampled sediment or ice. Urban collections are generally not representative regarding the type of spectrum, because the recognition of some micrometeorites or even entire types between the industrial dusts is difficult or in some cases almost impossible, at least according to current knowledge. For example, the types of CC, BO and PO, which are easier to recognize under a stereomicroscope, are usually very well represented, while the glass type (V) is less well represented due to the often-lacking magnetic properties of the mostly used method, as only specimens with metal droplets end up in the searched sample. Representatives of *G-type* and *I-type* are underrepresented or completely absent due to the weak differentiation characteristics compared to industrial spherules. The *scoriaceous* type is also rarely represented, the *unmelted* type very rarely or not at all. In both cases, the reason is confusion with optically similar, numerically far superior terrestrial particles. Of course, the level of knowledge of the processor plays a decisive role here.

The following diagram shows how representative urban micrometeorite collections can currently be.



Representativeness of an urban micrometeorite collection by comparison with abundance curves of different micrometeorite types in two Antarctic collections (assumed to be representative) and an urban collection and resulting gaps in coverage; sources: Suttle & Folco (2020), Genge et al. (2008)

6.2.6.3 The different micrometeorite types

The characteristic features of the different micrometeorite types are presented below with the aid of light and electron microscope images.

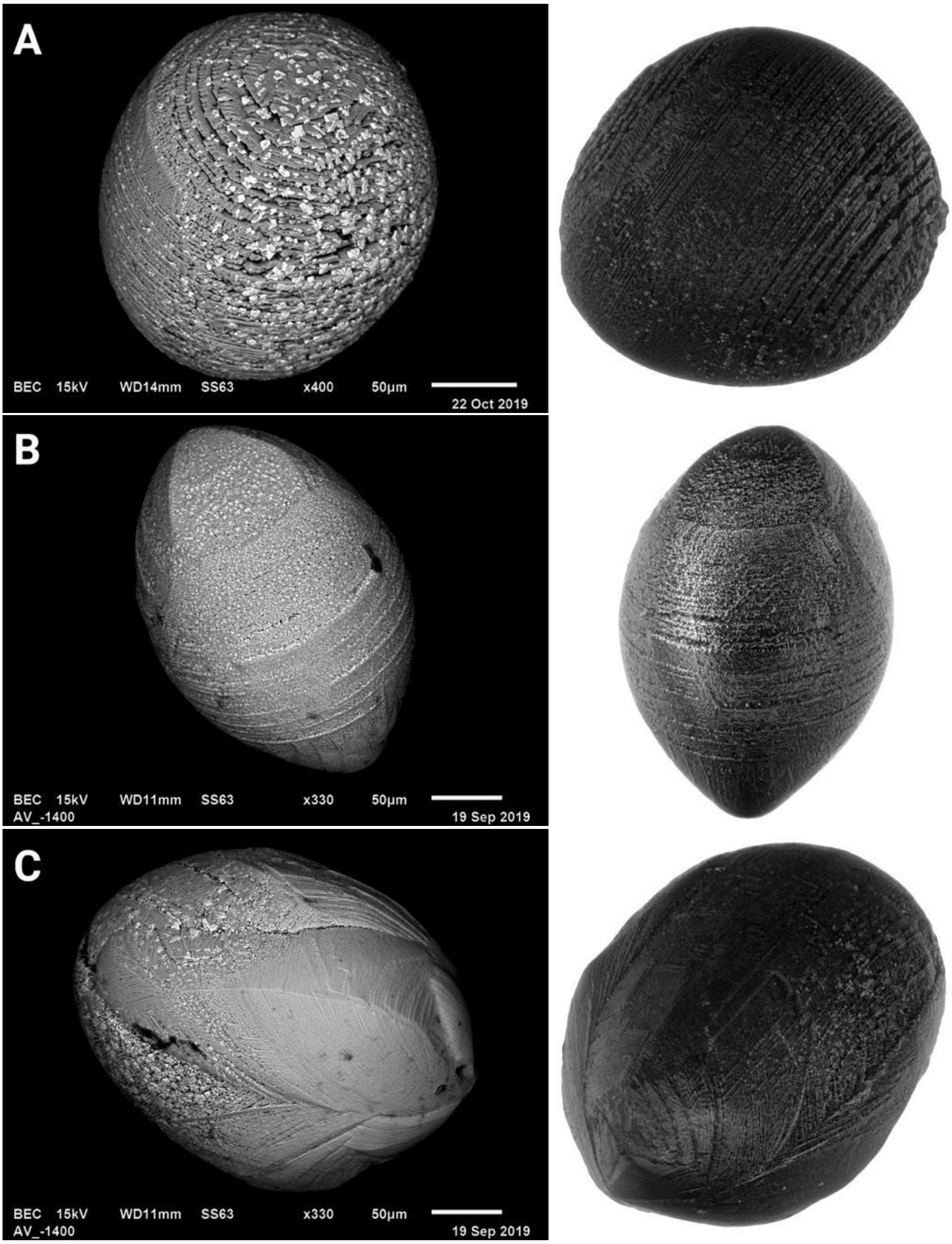
Barred Olivine (BO)

Barred olivine spherules are among the most common micrometeorites in urban dusts and the easiest to recognize under the stereomicroscope. They are rounded, often almost egg-shaped, dark gray to black, rather matt, whereby the light reflection and thus the shine and brightness of the particle can change by rotating the particle. Around 20-30 % of all micrometeorites > 100 µm are classified as type BO.

(*https://www.micrometeorites.org/galerie*)

Their structure is characterized by parallel bands of olivine crystals in a glassy matrix, usually interspersed with magnetite crystals.

The banded olivines can often already be recognized under the stereomicroscope at magnifications of 20x-50x, either directly as a very fine stripe pattern or indirectly through a changing light reflection behavior on the crystals when the particle is rotated, which allows its brightness to vary.



Different characteristics of the olivine crystal bands (left; electron micrograph, right: light micrograph of the same particle). ***A****: clear olivine bands several micrometers wide (THMM338);* ***B****: fine olivine bands barely wider than 1 µm (THMM229);* ***C****: gradual transition from coarser olivine bands to very fine bands to fine crystalline structure, which is why this micrometeorite can be classified as type Cryptocrystalline, subtype Microcrystalline (THMM220).*

Photographs of micrometeorites with different characteristics of the glassy matrix on the particle surface. In THMM573, the glassy matrix is largely absent, causing the olivine bands to stand out clearly. In THMM571, the glassy matrix is clearly pronounced, resulting in a rather smooth surface. (https://www.micrometeorites.org/galerie)

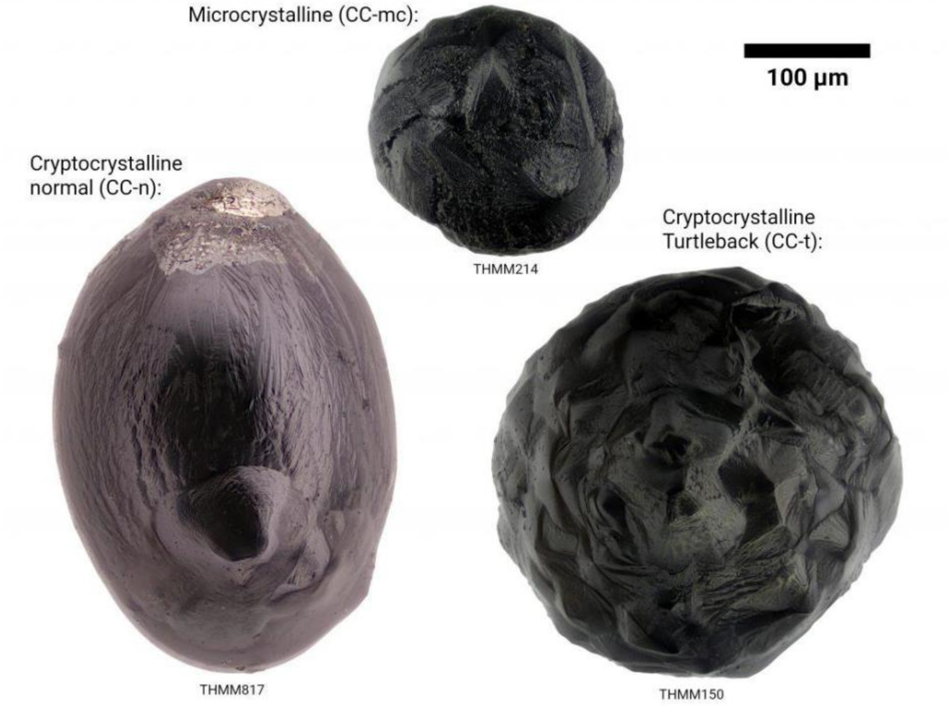
Cryptocrystalline (CC)

Micrometeorites of the **cryptocrystalline** type are optically diverse, both in terms of color, surface structures and shape. Around 20-30 % of all micrometeorites > 100 µm are categorized as type CC.

(https://www.micrometeorites.org/galerie)

They can be subdivided into three variants:

- Cryptocrystalline, **normal** variant (CC-n = CC-normal)
- Cryptocrystalline, **turtleback** variant (CC-t = CC-turtleback)
- Cryptocrystalline, **Microcrystalline** variant (CC-mc)



(*https://www.micrometeorites.org/galerie*)

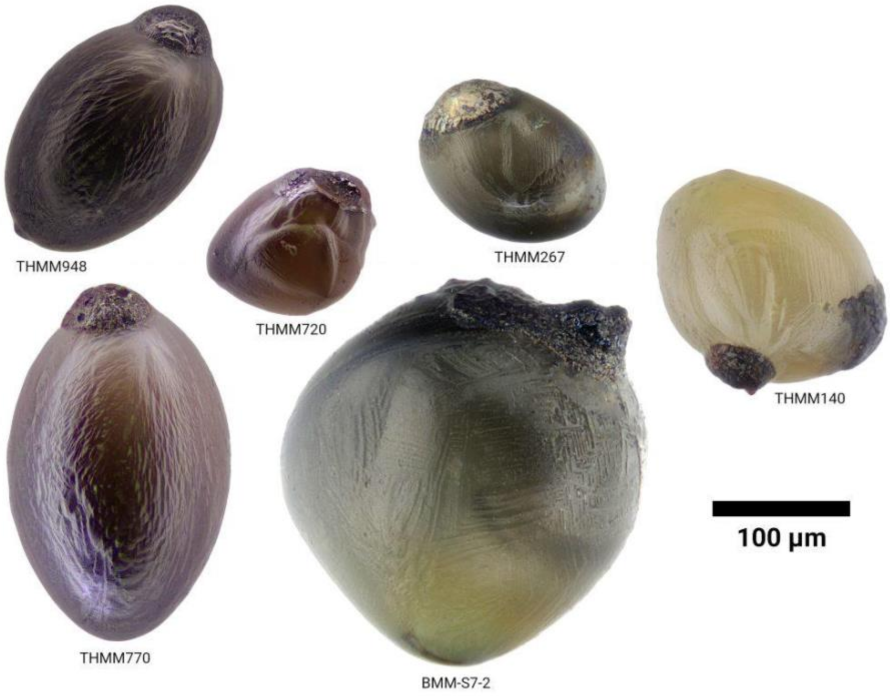
They are often characterized under the stereomicroscope by a shiny, smooth or very finely structured surface. They can usually be easily distinguished from urban spherules and are easy to recognize. Most spherule are dark grey to blackish, but it is not uncommon for them to have other colors.

Porphyritic (PO)

Porphyritic micrometeorites are among the richest in form. About 20-30 % of all micrometeorites > 100 µm are classified as PO type.

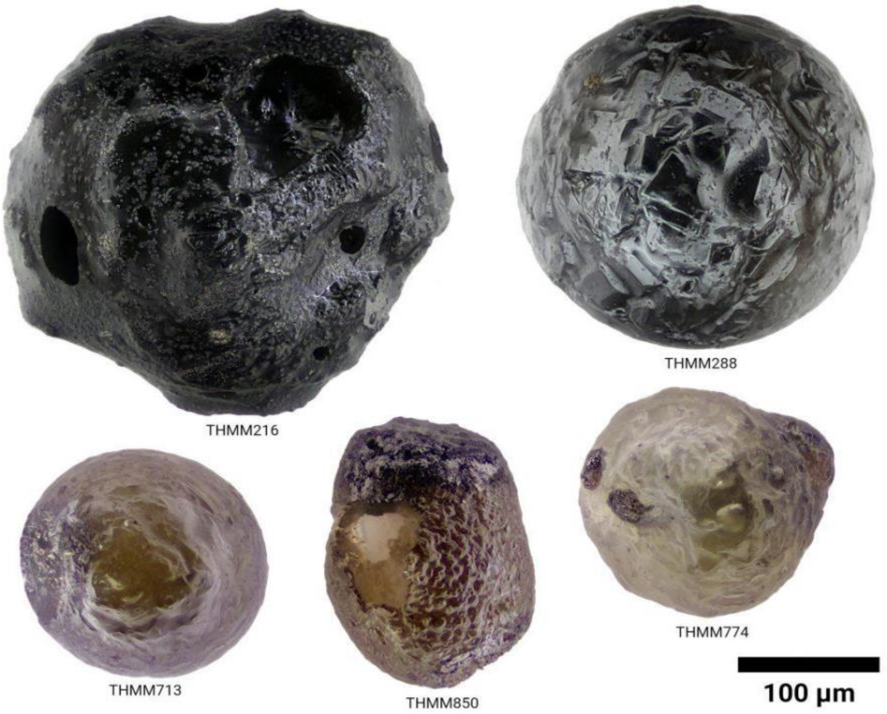
Colored representatives of the cryptocrystalline type, normal variant (CC-n) is mostly brown (THMM948, THMM770, THMM720), green (brown) (THMM267, BMM-S7-2) or ivory-colored (THMM140).

Most specimens are extremely deep black and shiny, which means that they can be distinguished from most terrestrial particles under the stereomicroscope. Occasionally, however, they are brownish, greenish or light brown to ivory-colored.



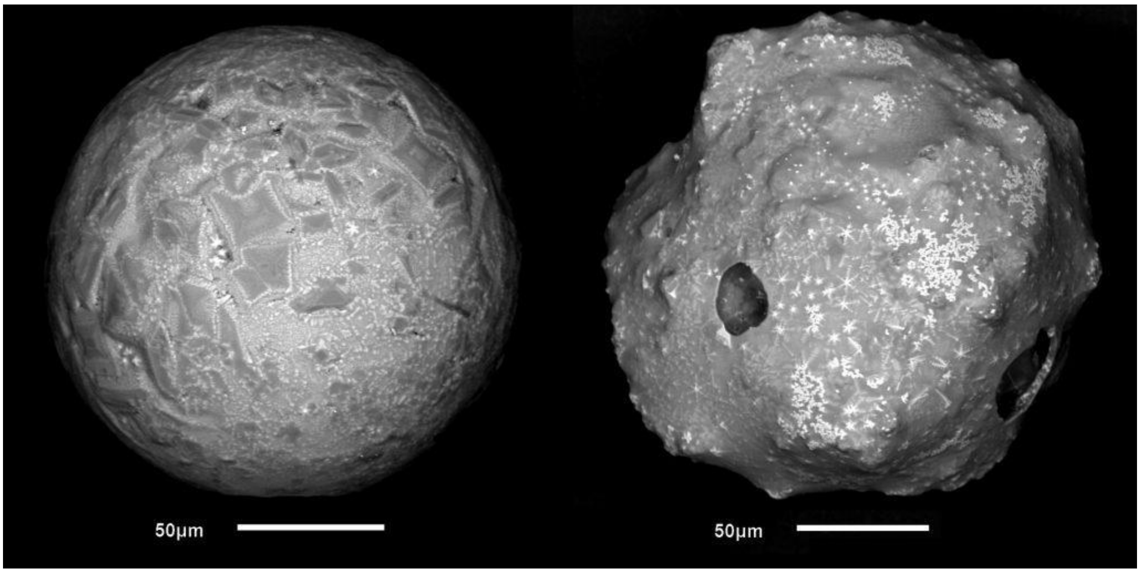
(https://www.micrometeorites.org/galerie)

(https://www.micrometeorites.org/galerie)



Black (THMM216, THMM288) and colored (THMM713, THMM774, THMM850) representatives of the Porphyritic (PO) type. (https://www.micrometeorites.org/galerie)

Large, randomly arranged, idiomorphic olivine crystals (i.e. with the characteristic crystal faces) embedded in a glassy matrix can often be recognized on the surface. In the absence of recognizable olivine crystals, other identifying features such as chromium-rich magnetites, individual chromite crystals or the overall chondritic element composition are helpful, whereby magnesium is sometimes strongly underrepresented in surface measurements.



Electron micrographs of two representatives of the porphyritic (PO) type: on the left [THMM238](#) with large idiomorphic olivine ($(Mg,Fe)_2SiO_4$) crystals (darker areas), on the right [THMM387](#) with chromium-rich branched magnetite crystals (light areas).

6.2.7 Where can be Micrometeorite found?

Micrometeorites, tiny extraterrestrial particles between 0.1 and 0.3 mm in size, can be found all over the Earth. However, locating them is challenging due to their small size and similarity to industrial dust. Optimal sampling locations have certain characteristics to maximize the concentration of micrometeorites:

1. Flat Roofs of Buildings:

- Dust accumulates over years, especially around drains and in corners.
- High roof edge trim profiles prevent wind from blowing away sediment.
- Plastic seal roofs are preferable as they don't contribute interfering particles.
- Older roofs tend to have more accumulated sediment.
- Roofs used only for maintenance and with low cleaning frequency preserve more sediment.
- Absence of surrounding trees reduces organic material interference.

2. Gutters of Buildings with Sloping Roofs:

- Gutters often retain sediment in depressions or blockages.
- Older, infrequently cleaned gutters with poor slope increase chances.

3. Gutter Drains:

- Magnetic traps can filter out metal-containing particles from draining water.
- These traps should remain installed for months for best results.

4. Rain Barrels:

- Sediment from roof gutters can deposit micrometeorites at the bottom of rain barrels.

5. Soil-bound Deposits:

- Found in places like street gutters, terraces, or balconies, though with lower concentration.
- Flat roofs are the most promising locations, with about 99% of recovered micrometeorites coming from them. Gutters and magnetic traps yield fewer micrometeorites, and soil-bound deposits can serve for methodological practice.

Other potential but less explored locations include lake sediments and snow after long dry periods.

6.2.8 Hunting for stardust - How to find your own Micrometeorites !

1. Put a magnet inside a clear plastic bag (like a sandwich bag or a polypocket). Most meteorites have iron in them which is attracted to magnets.

2. Drag the bag along the ground near gutters and water drains, collecting a reasonable amount of dirt on the outside of the plastic bag. (The micrometeorites get washed down the waterways by rainfall, so they are likely to be most common along gutters.)

3. After you have collected a reasonable amount of dirt on the outside of the plastic bag, get a clean piece of paper, hold the plastic bag above it and carefully remove the magnet. Brush the dirt off the outside of the plastic bag onto the piece of paper.

4. Using a sieve or fine gauze, sieve the dirt so that only the smallest particles remain.

5. Place these particles onto a microscope slide/petri dish and, using around 100x magnification, search for objects which are spherical. These are possible micrometeorites which form this shape as they are heated up and fall through the Earth's atmosphere.

For detailed information on Micrometeorite Search, see Micrometeorite Toolkit Manual.

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