Textural Analysis and Etching Calculation of Micrometeorites

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Masters of Science in Applied Geology

By

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "**Textural Analysis and Etching Calculation of Micrometeorites**" is based on the result of investigations carried out by me in the Masters of Science Degree in Applied Geology at the School of Earth, Ocean, and Atmospheric Science (SEOAS), Goa University under the supervision of Dr. Rudraswami N. G, Principal Scientist, Geological Oceanography Division, at CSIR-National Institute of Oceanography (CSIR-NIO), Dona Paula, Goa and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given the dissertation.

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ABBREVIATIONS USED

1. MM- Micrometeorite
2. CS- Cosmic Spherule
3. IDP- Interplanetary Dust Particles
4. CAT- Calcium Aluminium Titanium
5. CC- Cryptocrystalline
6. BO- Barred Olivine
7. PO- Porphyritic Olivine
8. UMM- Unmelted Micrometeorite
9. SMM- Scoriaceous Micrometeorite
10. SEM- Scanning Electron Microscope

ABSTRACT

Antarctica is located at the South Pole and has experienced distinct evolutionary processes and isolation over a significant geological duration. Its expansive ice sheet, formed gradually over time, serves as a repository preserving evidence of past glacial climate variations, protecting particles from weathering and dissolution including a detailed record of micrometeorite activity. Unlike terrestrial and deep-sea environments where micrometeorites undergo rapid weathering and dissolution in seawater, Antarctica's ice sheet acts as a protective shelter, safeguarding these materials in its cryogenic environment and hence the samples for micrometeorite analysis is often collected from Antarctica due to its preservation of extraterrestrial material under cryogenic conditions.

The pioneering study of micrometeorite samples MS-I6, MS-I7 and MS-I35 retrieved from Maitri station, which is the Indian station in Antarctica includes textural analysis and etching calculation of micrometeorites. It effectively provides samples of comets and asteroids that are rare survivors from the initially vast population of planetesimals. Micrometeorites offer a less biased representation of asteroids and comets due to their substantial arrival rate on Earth compared to traditional meteorites. Also, they interact with the upper atmosphere about 110-80Km from the earth’s surface, cosmic dust can tell us about the upper atmosphere. They also contribute to the ocean’s primary productivity as extraterrestrial dust is the source of bioavailable iron. The study further employs a comprehensive methodology encompassing sieving, drying, and magnetic separation of sediment samples to isolate prospective micrometeorites. These particles undergo meticulous manual selection, followed by embedding in epoxy, polishing, carbon coating, and subsequent examination via scanning electron microscopy (SEM) imaging and chemical compositional analysis using SEM-EDS. Utilizing ImageJ

software, a quantitative analysis of SEM images is conducted, particularly focusing on the textural characteristics to evaluate the degree of surface etching on cosmic spherules.

The current exploration delves deep into the intricate compositions of micrometeorites across samples MS-I6, MS-I7, and MS-I35, unveiling compelling insights. Porphyritic micrometeorites emerge as the predominant entities, comprising a substantial portion (approximately 44% to 49%) of the total micrometeorites recovered in each sample. In contrast, G-type meteorites consistently represent the minority, constituting only 1-5% of the samples analysed. Notably, G-type meteorites consistently exhibit higher average etching values across all three samples, indicating a heightened susceptibility to the effects of etching. This disparity stems from their distinctive composition, primarily composed of iron and nickel, rendering them more susceptible to erosion from cosmic rays and solar wind particles than the silicate-rich composition of porphyritic meteorites.

These findings underscore a compelling correlation between a micrometeorite's composition and its vulnerability to etching on Earth’s surface, shedding new light on the dynamic interplay between cosmic forces and celestial bodies.

CHAPTER 1

INTRODUCTION

1.1. MICROMETEORITES

Micrometeorites (MMs) are extra-terrestrial microscopic dust particles in the size range of approximately 10µm-2mm that have been captured by the Earth while moving in the interplanetary space of the Solar System (Rubin & Grossman, 2010) and are thought to represent samples of asteroids and comets mainly. They are specially produced via collisions among stable bodies and through floor evaporation of icy bodies inside the solar system consisting of asteroids, comets, and probably terrestrial planets and their moons. The majority of this extraterrestrial dust reaching the Earth's surface is believed to have sourced mainly either from asteroid belt or cometary bodies (Bradley et al., 1988; Maurette et al., 1991; Brownlee et al., 1993; Taylor et al., 1998; Genge et al., 2008). Collisions within the main asteroid belt significantly contribute to extraterrestrial dust in Earth's resonance orbit. These frequent impacts generate micron-sized particles entraining Earth's orbital path (Verniani, 1969). The extraterrestrial dust enters the Earth's atmosphere at a velocity range between ~11 km/s to ~72 km/s and suffers hypervelocity impact heating. Micrometeoroids, tiny meteoroids that survive the friction of entering Earth's atmosphere at extreme speeds, can be found on the planet's surface (e.g., Genge et al., 2008). Extraterrestrial material that hits the upper atmosphere as dirt is predicted to be about ~40,000 tons/annum (Love & Brownlee 1991). Cosmic dust contributes substantially to the total budget of the annually accreting extraterrestrial material on Earth. This dust constitutes samples from diverse near-Earth dust complexes. Previous studies show that a large quantity of this dust entering the atmosphere vaporizes as ablative loss upon entry, and a small fraction that survives spreads across the surface of the Earth (Taylor et al., 1998). These survived particles mostly accumulate as melted cosmic spherules that due to their strong endurance, are dominantly recovered out of different types of sedimentary concentrations on Earth's surface (Crozier, 1960; Deutsch et al., 1998; Taylor & Brownlee, 1991; Mutch, 1966; Jehanno et al., 1988; Czajkowski et al., 1983; Fredriksson & Gowdy, 1963).

Studies have shown that two distinct populations of micrometeorites are recovered from the Earth's surface and interplanetary dust particles (IDPs) collected in the stratosphere.

The large micrometeorites (~30–one thousand μm) recovered from the Earth's surface, are especially amassed through filtering of melted Antarctic ice and snow (Duprat et al., 2003; Iwata & Imae, 2001; Maurette et al., 1991; Taylor et al., 1998; Yada & Kojima 2000) have the most strong mineralogical and chemical affinities with the carbonaceous chondrites, and thus appear to be derived principally from asteroids (Genge et al., 1997a; Kurat et al., 1994) although cometary substances also are present (Engrand & Maurette 1998a; Nakamura et al., 2005).

The diminutive size of the extraterrestrial dust particles offers limited insights into the composition and history of their parent bodies. Meteorites indicate that even the most primitive are relatively heterogeneous on scales equivalent to the dimensions of MMs since they comprise chondrules, refractory inclusions, and fine-grained matrices. While individual asteroidal micrometeoroids (MMs) may be small, they offer us a glimpse into the makeup of their parent bodies. These MMs can represent various components, including the surrounding matrix, embedded chondrules, or even heat-resistant refractory inclusions (Genge et al., 1997a; Kurat et al., 1994). In contrast, even though anhydrous IDPs are mineralogically notably homogeneous at scales larger than tens of microns (Rietmeijer 1998), the character of cometary substances is uncertain.

Meteorite-like substances additionally arise some of the smaller particles (<30 μm) collected directly from the Earth's stratosphere. However, around 40% of IDPs, known as anhydrous IDPs, are very different from meteorites and are highly volatile-rich. It has been suggested that these are derived from comets (Bradley, 1994; Rietmeijer, 1998). Extra-terrestrial dust particles collected in the stratosphere have come to be known as interplanetary dust particles, whereas those recovered from the Earth's surface are most referred to as micrometeorites.

Previously, only particles survived (Whipple, 1951); however, because of the gradational nature of melting, all extra-terrestrial dust particles that survive to reach the Earth's surface, including melted particles, are here classified as MMs.

They are broadly classified according to the degree of melting experienced during atmospheric entry as melted micrometeorites or cosmic spherules, unmelted or angular micrometeorites, and partially melted or scoriaceous micrometeorites. Although most micrometeoroids impacting the Earth's atmosphere are lost through melting and evaporation, micrometeorites constitute the principal source of extra-terrestrial material that can be recovered to the Earth's surface (e.g., Taylor et al., 1998; Yada et al., 2004). Extra-terrestrial particles smaller than 10 mm are usually collected in the stratosphere and are known in the literature as Interplanetary Dust Particles, IDPs (e.g., see Rietmeijer, 1998; Jessberger et al., 2001; Bradley, 2007).

1.2. <u>Classification of Micrometeorites</u>

Micrometeorites are classified into three main groups and can be identified based on their preatmospheric textures:

1.2.1. **Melted Micrometeorites: Cosmic Spherules**

Melted micrometeorites are categorised as round to sub-round particles (whence the synonym of cosmic spherules; CS) formed as molten droplets throughout the atmospheric entry. There has been total melting experienced (or nearly so) of the micrometeoroid primary phases during atmospheric entry and thus behave as low-viscosity melts. Cosmic spherules (CSs) display a sizeable variety in textures, compositions and mineralogy and may be subdivided into numerous chemical and textural groups. The basic compositional subtypes of CSs, which are also reflected in their principal mineralogy, are the Fe-rich spherules (I-type), silicate-rich spherules (S-type), and the spherules which are mixtures of the above spherules (G-type).

1.2.1.1. The **S-type CSs** with aid using ways the maximum common, making up 97% of 1600 cosmic spherules analysed from the South Pole Water Well (Taylor et al. 2000). The majority of micrometeoroids exhibit compositions consistent with meteoroids originating from chondrites (Brownlee et al., 1997). However, a distinct exception exists: CAT spherules deviate from this norm by displaying elevated magnesium-to-silicon ratios (greater than 1.7) and enrichments of calcium, aluminium, and titanium (Taylor et al., 2000). The S-kind CSs are ruled with the aid of using olivine micro phenocrysts, and silicate glass and regularly include magnetite and/or chromite. They can also include relict grains, basically Mg-wealthy pyroxene, and olivine, that survived melting inside the environment and once in a while have FeNi metal droplets.

S-type spherules may be subdivided into numerous subclasses relying on their quench textures, which are thought to reflect their peak atmospheric temperatures (Taylor et al., 1991). The subtypes are as follows: glass or vitreous

(V), cryptocrystalline (CC), barred olivine (BO), and porphyritic (PO) spherules.

1.2.1.1.1. **<u>Glass spherules</u>** are thought to have formed at the highest peak temperatures and lack olivine microphenocrysts. When seen under the binocular microscope, these are transparent brown, yellow, or green and go extinct under crossed polarization. These spherules now and then incorporate huge vesicles. They are typically spherical and may be pretty vesiculated, and a few include FeNi steel beads and need to be no longer pressured with the G-kind spherules defined above.

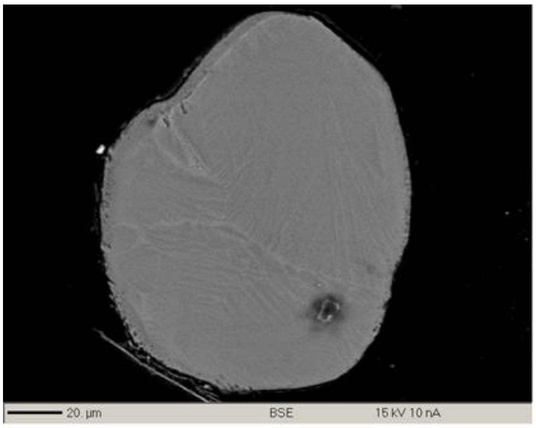

Figure 1.1: SEM Image of Glass Spherule (S-type).

1.2.1.1.2. **<u>Cryptocrystalline (CC) spherules</u>** have incredible submicron magnetite and comprise submicron crystallites. There are two different textures. Olivine microcrystals can develop from the floor inward by generating a knobbly floor. Other cryptocrystalline spherules have numerous areas that crystallise concurrently, generating extraordinarily fine-grained areas surrounded by a greater iron-wealthy phase. CC spherules are notion to have fairly decreased height temperatures than glass spheres due to the fact a number of the crystallization nuclei survive (Brownlee et al., 1991).

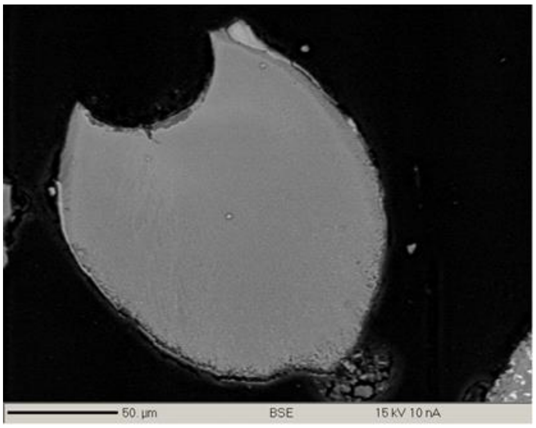

Figure 1.2: SEM Image of Cryptocrystalline Spherule (S-type).

1.2.1.1.3. **Barred olivine (BO) spherules** are influenced by parallel-growth olivine, seen as parallel bars in polished sections, inside a glassy mesostasis that frequently carries magnetite. Most BO spherules have egg-like (ovoid) shapes that are without difficulty diagnosed below a binocular microscope, even though a few are elliptical. These spherules are usually opaque under a binocular microscope, except for those containing a metal/ferrihydrite bead, which is often brown/green in transparency. Some BO spherules showcase FeNi metal beads that have now and then been oxidized to shape iron oxide, frequently with a cubic morphology, positioned at one end of the particle.

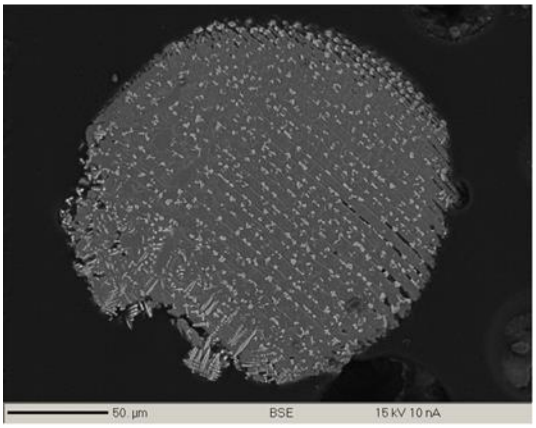

Figure 1.3: SEM Image of Barred Olivine Spherule (S-type).

1.2.1.1.4. **<u>Porphyritic olivine (PO) spherules</u>** are dominated by the use of microphenocrysts of olivine with equant, euhedral, or skeletal morphologies inside a glassy mesostasis, usually with accessories such as magnetite and/or chromite. Relict olivine (and rarely pyroxene), often with overgrowths of more Fe-rich olivine grown from the melt, is common in PO spherules, together with the olivine microphenocrysts, which suggest ample crystallisation nuclei, suggesting that PO spherules experienced the lowest peak temperatures of any cosmic spherules, mainly those that comprise relict minerals. Porphyritic spherules show considerable crystallinities and sizes. Those with the smallest microphenocrysts tend to be the most vesicular and are likely to be gradational to partly melted MMs. Some PO spherules also contain areas dominated by Fe-Ni-ferrihydrite and/or Ni-bearing sulphides. These are thought to form as immiscible metallic liquids during heating and are often found at the margins of spherules, suggesting they were in the process of separating during cooling (Genge et al., 1998a).

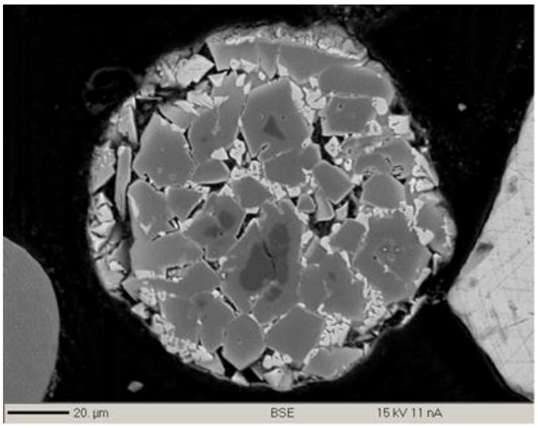

Figure 1.4: SEM Image of Porphyritic Olivine Spherule (S-type).

1.2.1.2. **<u>I-type CSs</u>** are dark-coloured, opaque spheroids with a distinctively metallic lustre under the stereomicroscope. FeO dominates them with minor amounts of other oxides (principally MgO and SiO2), mineralogically they are dominated by magnetite crystals with wüstite intergrowths, however, Ni-rich iron metal, now and then with a nugget of the platinum group of elements, can arise as spheres inside spherules. In section, I-kind spherules might also additionally display an abnormal void of their centres, probably because of the speedy crystallization of the soften from the floor inwards (Feng et al., 2005). I-type spherules sometimes contain Ni-rich Fe and Ni metal beads. The expulsion of those metallic beads via means of the differential acceleration of immiscible liquids with contrasting densities during atmospheric flight may leave an eccentric spherical void. I-type spherules are plentiful in deep sea collections, as they are very immune to weathering, however, they represent only 2% of 1600 cosmic spherules amassed at the lowest of the South Pole Water Well (SPWW) (Taylor et al., 2000). Some I-type spherules can also comprise modest quantities of silicate glass. Their most important detail bulk composition is ruled via way of means of FeO and Fe2O3, with NiO up to ~7—five wt.% (Engrand et al., 2005).

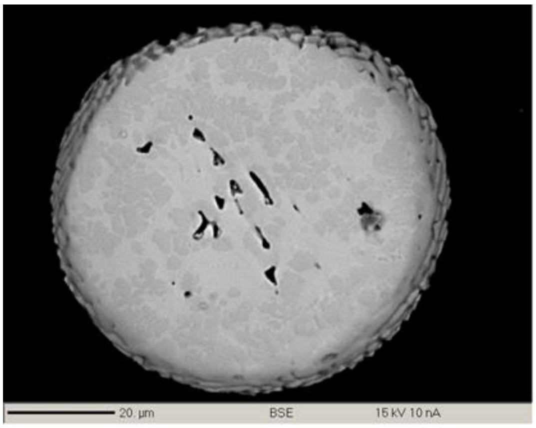

Figure 1.5: SEM Image of I-type CS.

1.2.1.3. **G-type CSs** are matt dark, opaque spherules under the stereomicroscope. They have major intermediate element compositions between the broadly chondritic S-type spherules and the I-type CSs. G-type spherules are typically dominated by magnetite dendrites within a mesostasis of silicate glass matrix, some have subspherical voids like those found within I-type spherules which may likewise have formed by the loss of metal beads. G-type spherules, however, may have an extensive variety of textures and consist of debris that ranges in texture and mineralogy from common spherules. The common major-detail and trace-detail compositions of cosmic spherules, respectively, S-, I- and G-kind spherules are discriminated with the aid of using their Si: Mg: Fe atomic, with S-kind spherules displaying special ratios usual of ultrabasic and secondarily fundamental rocks, I-kind plotting on the Fe vertex, and G-kind displaying intermediate compositions. However, the restrained database for G- and I-kind spherules can also cover a bulk compositional continuum among the 3 types.

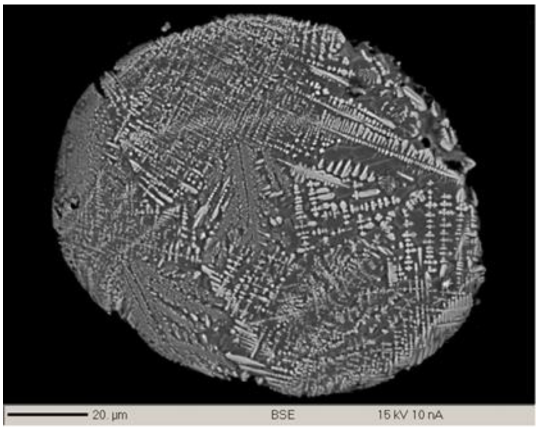

Figure 1.6: SEM Image of G-type CS.

CAT spherules, have barred olivine textures, lack Fe, have high Mg/Si ratios, and have high Ca, Al, and Ti values. These seem white beneath the microscope and the climate fast inside the acidic Antarctic meltwater (Taylor et al., 2000). Isotopic analyses (Mg, Si, and O) affirm that they have partially evaporated in the course of atmospheric access heating (Alexander, 2002), and in comparison, to all different S-kind spherules, they have been subjected to the highest temperatures.

Cosmic spherules, while often melted during atmospheric entry, can preserve relic minerals like forsterite enstatite pyroxene and olivine. These minerals offer valuable clues about the parent bodies from which the spherules originated. However, now and again, Fe-rich types are found and diagnosed by greater Mg-rich overgrowths. The abundance of relict grains varies significantly from the ones containing small volumes of remoted grains, regularly gifted as cores, to olivine microphenocrysts grown from the melt, to spherules in which relicts are volumetrically dominant. The latter debris likely constitutes melted coarse-grained or composite debris (see beneath for a definition of those materials) and are, thus, wonderful from different CSs that shape with the aid of melting fine-grained particles.

The presence of relict minerals inside CSs has to be denoted via way of means of the prefix “relict-bearing” (Taylor et al., [1998]). Those spherules that appear to have formed by the melting of a coarse-grained precursor should be described as CG spherules. Two distinct types of cosmic spherules exist: those packed with unusually high volumes (>25%) of relic grains, and those with compositions deviating from the typical chondritic makeup. The latter suggests they formed from the melting of a precursor body with a coarse-grained structure.

1.2.2. <u>Unmelted Micrometeorites (UMMs)</u>

Unmelted Micrometeorites survive atmospheric entry with minimal alteration, they provide direct evidence for their parent bodies.

1.2.2.1. **<u>Fine-grained MMs (Fg-MMs)</u>**, which can be ruled through a fine-grained porous groundmass of micron-sized mineral grains, and

1.2.2.2. **<u>Coarse-grained MMs (Cg-MMs)</u>**, which might be ruled by using anhydrous silicates with grain sizes larger than numerous microns, regularly with glassy mesostasis.

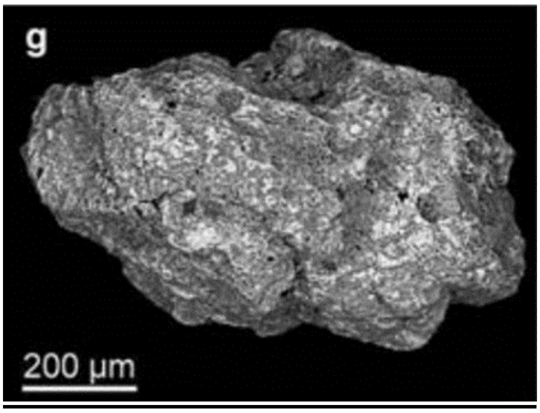

Figure 1.7: SEM Image of Unmelted MM (Folco, L., & Cordier, C. (2015).

1.2.3. <u>Scoriaceous Micrometeorites (SMMs)</u>

Scoriaceous micrometeorites are a type of micrometeorite that has been partially melted during its entry into Earth's atmosphere.

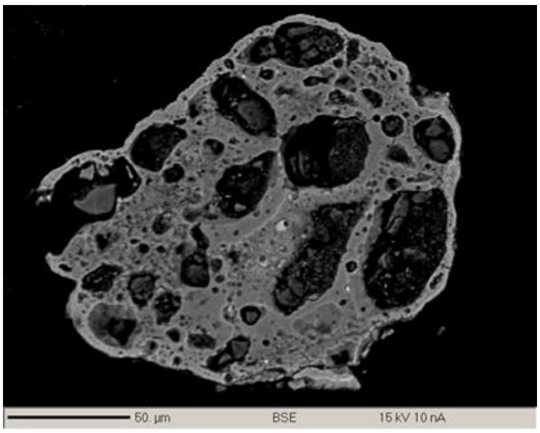

Figure 1.8: SEM Image of Scoriaceous MM.

1.3. Etching

Etching is the weathering of MMs due to chemical, mechanical or biological processes. The etching process can alter the shape and surface texture of micrometeoroids, and can also lead to the loss of material. The extent of etching depends on several factors, including the size and composition of the micrometeorite, the duration of its exposure to space, and the specific conditions in the space environment it has encountered.

1.4. AIMS AND OBJECTIVES

a) To determine the chemical characteristics of MMs from Antarctica.

b) Textural Analysis of Cosmic spherules from Antarctica.

c) Etching Calculation of MMs from Antarctica.

CHAPTER 2

LITERATURE REVIEW

2.1. SIGNIFICANCE OF MICROMETEORITES

Micrometeorites offer unique insights into the early solar system's composition and evolution. As remnants of the once-abundant population of planetesimals, they provide samples of comets and asteroids that survived from this primordial era. Unlike larger meteorites, which may exhibit biases towards certain compositions, micrometeorites offer a less biased representation of small celestial bodies due to their substantial arrival rate on Earth. Moreover, their smaller size increases survivability during atmospheric entry, preserving their original composition and structure effectively. Continuous influx over geological timescales ensures a steady supply of samples for scientific study, leading to a more accurate understanding of asteroid and comet distribution and evolution.

In addition to their significance in planetary science, micrometeorites interact with Earth's upper atmosphere, shedding light on its properties and dynamics. As these particles enter the atmosphere, they undergo processes such as atmospheric heating and ablation, generating luminous trails known as meteors. The study of these trails informs scientists about upper atmospheric conditions such as density, temperature, and composition. Furthermore, the interaction of micrometeorites with the atmosphere releases ions that influence the ionosphere's electrical properties, aiding in the study of plasma dynamics and atmospheric chemistry.

Extraterrestrial dust, including micrometeorites, also plays a vital role in Earth's marine ecosystem by providing bioavailable iron. This influx of iron stimulates phytoplankton growth, which serves as a crucial carbon sink, mitigating atmospheric carbon dioxide levels and regulating Earth's climate. Increased primary productivity resulting from extraterrestrial dust deposition supports marine biodiversity and fisheries, highlighting the interconnectedness of cosmic events with terrestrial ecosystems. Overall, micrometeorites and extraterrestrial dust contribute valuable insights into planetary science, atmospheric dynamics, and Earth's ecological balance.

2.2. PREVIOUS STUDIES RELATED TO MICROMETEORITES

The 2008 study by Genge et al. delves into the classification of micrometeorites, tiny extraterrestrial dust particles captured by Earth. These particles are believed to offer insights into the composition of asteroids and comets. The study outlines the difficulties in classifying micrometeorites due to their minute size and emphasizes the importance of grouping them based on their mineralogical, textural, and chemical properties, which reflect differences in their parent bodies. To address these challenges, the study proposes a unified classification system based on observations of thousands of micrometeorites collected from Antarctic ice. Micrometeorites are categorized into melted, partially melted, and unmelted groups, depending on their mineralogical and textural characteristics. The proposed classification system aims to provide a meaningful framework for understanding the genetic relationships between different micrometeorite groups. Additionally, the study discusses non-isotopic criteria used to confirm the extraterrestrial origin of micrometeorites and distinguishes them from similar particles like meteorite ablation spheres and microtektites.

In summary, the research comprehensively examines the challenges associated with classifying micrometeorites and proposes a unified system to address these challenges. It also discusses criteria for confirming their extraterrestrial origin and differentiating them from other particles of similar origin.

Luigi Folco and Carole Cordier's 2015 research "Micrometeorites” provides a thorough examination of micrometeorites, covering their origin, characteristics, and collection techniques, offering crucial insights into the study of extraterrestrial materials in planetary science and astrophysics. It highlights the annual deposition of approximately 40,000 tonnes of micrometeoroids on Earth, predominantly interplanetary dust resulting from Solar System celestial body collisions. Surviving hypervelocity impacts with Earth's upper atmosphere, these micrometeoroids are collected as micrometeorites on the Earth's surface, providing samples for laboratory analysis from various Solar System dust-producing bodies.

The systematic analysis of micrometeorite collections enables the exploration of extraterrestrial input cycles into Earth's global geochemical budget and their potential impact on life emergence. Additionally, it aids in modelling the source regions and dynamic evolution of cosmic dust in near-Earth space, along with assessing potential hazards posed by dust to space activities. The study introduces a classification system for micrometeorites based on their degree of melting during atmospheric entry, categorizing them into melted micrometeorites (cosmic spherules), partially melted or scoriaceous micrometeorites, and unmelted micrometeorites. Detailed descriptions of their morphological, petrographic, and compositional features provide insights into their mineralogical and textural properties. Furthermore, the classification distinguishes between chondritic and differentiated spherules based on bulk elemental compositions, offering insights into their origins and processes. Moreover, the study discusses various collection environments for micrometeorites, including deep-sea sediments, polar ice and snow, and loose sediments on mountain peaks, emphasizing their importance in understanding micrometeorite flux over time. It stresses the necessity of new, large, and representative collections to provide precise area-time constraints for calculating micrometeorite flux, devoid of contaminants, and utilizing non-selective sampling methods.

In conclusion, the research serves as a comprehensive resource for understanding the nature, classification, and significance of micrometeorites, thereby advancing our knowledge of the composition and dynamics of the Solar System and its potential implications for Earth and space activities.

The research from 2016 discusses the weathering of micrometeorites found in the Antarctic environment, aiming to distinguish primary and secondary features. The study is based on the analysis of 366 particles from Larkman Nunatak and 25 from the Transantarctic Mountain collection. The weathering effects identified include irregular and faceted cavities, surface etch pits, in-filled cavities, replaced silicate phases, and hydrated and replaced metal. The level of weathering is observed to be responsive to variations in primary mineral composition and displays notable variability across different particle types. The compositions and textures of weathering products suggest open system behaviour and variable water-to-rock ratios, indicating climatic variation over the lifetime of the micrometeorite deposits. Various morphological categories of weathering effects were observed, such as irregular and faceted cavities within particles, indicating congruent dissolution of silicate phases, particularly olivine, as important in generating new pore space. The precipitation of new hydrous phases within cavities, such as ferrihydrite and jarosite, results in pseudomorph textures within heavily altered particles. The selective dissolution of silicate minerals represents a terrestrial weathering phenomenon observed across various locations, including deep-sea sediments, Greenland, the South Pole Water Well, and the Transantarctic Mountains. The study introduces the inaugural thorough examination of micrometeorite weathering at Larkman Nunatak, Antarctica. Additionally, it unveils the premier weathering scale for Antarctic micrometeorites, which assesses both terrestrial alteration and encrustation by secondary phases.

The results detail the recognition of various weathering characteristics such as irregular and faceted cavities, etch pits, and in-filled cavities. These findings prompt discussions on how they affect determining micrometeorite weathering rates, preservation, and abundance, as well as the environmental factors influencing micrometeorite weathering. Furthermore, the study provides insights into the chemical weathering of the main mineral phases in micrometeorites, particularly olivine, and the associated effects on the preservation of micrometeorites. The comprehensive analysis and categorization of the weathering effects contribute to a better understanding of the terrestrial alteration of micrometeorites and its implications for the estimation of the flux of extraterrestrial matter to the Earth’s surface. Overall, the document presents a detailed exploration of the weathering processes affecting micrometeorites in the Antarctic environment and offers valuable insights into the factors influencing their preservation and abundance.

In 2020, Rudraswami, Fernandes, and Pandey investigated the characteristics of extraterrestrial dust particles that make their way to Earth's surface. The collection of MMs (>50μm) obtained from ice melting near Maitri station in Antarctica reveals a large quantity of material in the 80-140μm size range. The smaller particles typically undergo atmospheric entry heating, contrary to earlier observations suggesting they reach the Earth's surface unmelted. Chondrules and refractory inclusions are rare, suggesting a slow ice accumulation rate of less than 1.0 g cm2 yr-1.

The research focused on understanding the extraterrestrial dust accretion by the Earth's surface, which is crucial for understanding the micrometeoroid complex. The study aimed to understand the flux and types of particles from the recent collection near Maitri station, Antarctica, an Indian station. The sample collection was done from blue ice located near the station. The estimation of the extraterrestrial flux over time is limited, and it is unknown if it has been relatively constant since the origin of the solar system. The study used electron microscopy to analyse the petrographic textures of 3 tons of ice (MS-I3, MS-I4, MS-I35) and found a considerable large number of micrometeorites (~1300 particles). These cryoconites, which are dust particles accumulated from nearby areas, grow in size depending on the absorption of heat and melting of the ice, moving material from one region to another through small water channels The cumulative weight of micrometeorites (MMs) exceeds that typically observed in ice samples lacking visible cryoconites. The chemical composition of the identified phases and bulk analyses of major elements from the micrometeorites are analysed using an electron probe microanalyzer with four spectrometers at the National Institute of Oceanography (NIO), Goa, India. The results show that the chemical composition of the micrometeorites is much larger than in usual ice samples without visible cryoconites. The investigation contributes to our understanding of the release of dust from precursor bodies to entry into Earth's atmosphere and their survival as micrometeorites (MMs) on Earth's surface.

The 2021 study by N. G. Rudraswami et al. delves into the importance of extraterrestrial dust as a provider of bioavailable iron to the ocean, stimulating primary productivity. The study emphasizes the essential role of bioavailable iron in supporting phytoplankton growth and drawing down atmospheric CO2. It provides insights into the partitioning of extraterrestrial iron between seawater and sediments, estimating the contribution of surviving particles and meteoric smoke particles. The research sheds light on the dissolution and alteration of cosmic spherules recovered from deep-sea sediments and Antarctica, highlighting the substantial impact of extraterrestrial dust on the ocean's biogeochemistry.

The study reveals that extraterrestrial dust, particularly micrometeorites and meteoric smoke particles, plays a vital role in supplying bioavailable iron to the oceans, impacting primary productivity. It examines the composition and mineralogy of extraterrestrial dust recovered from deep-sea sediments and Antarctica, providing valuable data on the abundances and compositions of various types of cosmic spherules. The findings demonstrate the complex nature of extraterrestrial dust, including surviving particles and meteoric smoke particles, and their contribution to the bioavailability of iron in the marine environment. Additionally, the study addresses the uncertainties surrounding the average Fe content of incident dust, the proportion of Fe delivered by surviving micrometeorites, and the relative importance of meteoric smoke particles. Furthermore, the research delves into the burial of extraterrestrial Fe in ocean sediments, underscoring the significant effects of dissolution observed within recovered cosmic spherules. It highlights the geographic variation in the flux of meteoric smoke particles and surviving micrometeorites to the Earth's surface, emphasizing the regional inputs of iron to the oceans. Overall, the study provides valuable insights into the role of extraterrestrial dust as a source of bioavailable iron, contributing to the ocean's biogeochemistry and driving primary productivity. The findings contribute to a better understanding of the complex interactions between extraterrestrial materials and marine ecosystems, with implications for global climatic conditions.

Lastly, the study offers a comprehensive analysis of the intricate relationship between extraterrestrial dust, bioavailable iron, and primary productivity in marine environments. The research findings contribute to a deeper understanding of the role of extraterrestrial materials in Earth's biogeochemical processes, shedding light on their impact on marine ecosystems and global climate dynamics.

In 2021, D. Fernandes, N.G Rudraswami, M Pandey and M Kotha presented findings on the chemical composition of 176 glass spherules sourced from blue ice in Antarctica and deep-sea sediments in the Central Indian Ocean Basin. This study compared the chemistry of these glass spherules from different reservoirs, allowing for an examination of potential biases and efficiencies in various collection methods. Among the S-type cosmic spherules, the glass spherules have undergone extensive heating, leading to a significant loss of ablative elements, the origins of which remain uncertain. Previous model calculations suggested that the chemical alterations in the glass spherules were due to atmospheric entry, while earlier heating experiments shed light on their formation processes. They identified Ca–Al glass spherules with elevated CaO+Al2O3 content, indicating larger particles with excessive evaporation of moderate volatiles (Fe, Si, Mg), resulting in refractory (Ca, Al) enriched glass or the equilibration of minor Ca and Al phases in the glass. Morphologically distinct glass spherules from Antarctica and the deep sea have largely ablated elemental Fe during atmospheric entry; however, their bulk chemical composition and atomic ratios showed broad similarities with carbonaceous chondrites, preserving precursor properties.

CHAPTER 3

METHODOLOGY

3.1. STUDY AREA

Micrometeorite samples for investigation included in this study are collected from Antarctica as the Antarctica ice sheet serves as the storehouse, preventing micrometeorites from getting corroded rather than preserving material under its cryogenic conditions and hence is a promising region for micrometeorite collection. They can also be collected from the Central Indian Ocean Basin.

3.1.1. Antarctica

The continent of Antarctica, situated on the South Pole, has undergone independent evolution and isolation over a considerable geological timeframe. Its vast ice sheet, which has gradually developed over time, can retain evidence of past glacial climate changes, including a systematic record of micrometeorite flux. In contrast to terrestrial and deep-sea environments, where micrometeorites are prone to rapid weathering and dissolution in seawater, Antarctica's ice sheet acts as a preservation repository, safeguarding these materials under its cryogenic conditions. The dating of ice cores extracted from the Vostok station suggests that the slowly expanding Antarctica ice sheet has been accumulating extraterrestrial dust for approximately 50 million years. Furthermore, due to the absence of anthropogenic activities, Antarctica provides an ideal setting for conducting scientific research on palaeoclimatology and extraterrestrial dust.

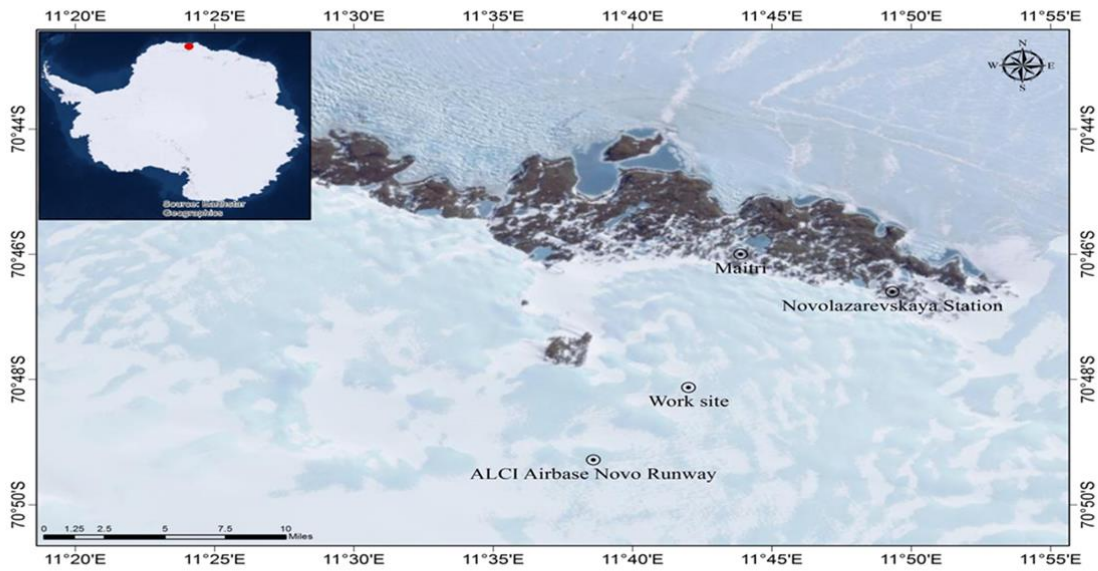

Figure 3.1: Map of Study Area (Rudraswami et al., 2018,2020).

3.1.2. <u>Central Indian Ocean Basin</u>

The Indian Ocean is the 1/3 biggest ocean in the Asian continent in the north, the Atlantic Ocean and African continent in the west, the Australian continent and the Pacific Ocean in the East, and the Antarctica continent in the south. The vast extent of the Indian Ocean with a total global area coverage of 70,560,000 km² constitutes a productive reservoir for micrometeorite assortment. Micrometeorites from the deep sea were extracted from sediments that were recovered from ~5000m water depth. The sediment samples out of a total area measuring ~150x200 km from the Central Indian Ocean Basin (CIOB), were swept to collect polymetallic nodules along which the sediments were also recovered during a polymetallic nodule expedition that was carried out using Akademik Aleksandr Sidorenko Russian research vessel chartered by the Government of India. All 10 sediment sampling operations were performed using grab samplers. The grab sampler has a collection capacity of ~45kg (wet weight) of sediment and covers an area of 50x50 cm of the sea floor. In effect, a total carpet area of 2.5 meters square of the seafloor was mined. The sediments have been sieved in 200µm length mesh onboard. In all, ~3 tons of sediment were recovered.

3.2. METHODOLOGY

The proposed methodology is summarised below: -

In this study, sediment samples are sieved, dried, and magnetically separated to isolate potential particles from sediments. Possible particles are handpicked by fine brush under the binocular microscope and will be mounted in epoxy to prepare mounts. The epoxy mount will be polished until it exposes its internal features. Then, the polished mount would be carbon-coated and subjected to SEM imaging for textural examination. The chemical compositional analysis will be carried out with the help of SEM-EDS. Scanning Electron Microscope (SEM) images are then analysed using ImageJ software to quantify the extent of etching on the cosmic spherule's surface.

1. Sample collection

Micrometeorite samples were collected from Maitri station in Antarctica.

2. Sieving and magnetic separation

The ice sample is melted using an infrared lamp and then the sediment samples are sieved using a mesh of 220 microns.

3. Magnetic Separation

Once the sieving is completed, the magnetic separation technique is used to separate the magnetic particles from the remaining sediments.

The magnetic separation technique is performed as follows:

i. Initially, sediments are spread out on a plastic sheet.
ii. A bar magnet is taken and covered using a cloth of 20 microns.
iii. After this, the magnet is moved over the spread-out sediments. During this process, magnetic particles get attracted to the magnet.
iv. Once the magnetic separation is complete, take out the bar magnet from the cloth and slightly tap the cloth so that any particles still attached to the cloth can fall onto the tracing paper on which the rest of the magnetic particles have been collected.
v. The magnetic particles collected on the tracing sheet are then transferred into the petri dish.

4. Picking of potential particles

Potential particles (micrometeorites) are picked by observing them under the stereomicroscope.

5. Mounting and polishing

These particles are mounted on the slide using double-sided tape. Then a small-sized cylinder is placed on top of the mounted particles and is sealed from the sides. In this cylinder, a mixture of epoxy hardener and epoxy resin is poured in a ratio of 1:4 respectively and left for about 8 hours to harden.

Once the mounts are hardened, they are polished to acquire a clean finish.

6. Labelling and marking

The mounts are then labelled and marked.

7. Ultrasonic cleaning

Ultrasonic cleaning is done at a frequency of 156 Hz and for about 40 seconds. Initially, the mounts are placed in distilled water then in alcohol and lastly in distilled water again.

8. Carbon coating

Carbon coating is done to make non-conductive samples conductive, which avoids charging effects and encapsulates samples to eliminate off-gassing or evaporation.

9. SEM (Scanning Electron Microscope)

The textural analysis of micrometeorite samples is done with the help of Jeol SEM. The SEM produces a largely magnified image by using electrons instead of light to form an image. A beam of electrons is produced at the top of the microscope by an electron gun. The electron beam follows a vertical path through the microscope, which is held within a vacuum.

10. Etching Calculation

The software ImageJ is used for etching calculations. ImageJ is a Java-based image processing program developed at the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation (LOCI, University of Wisconsin).

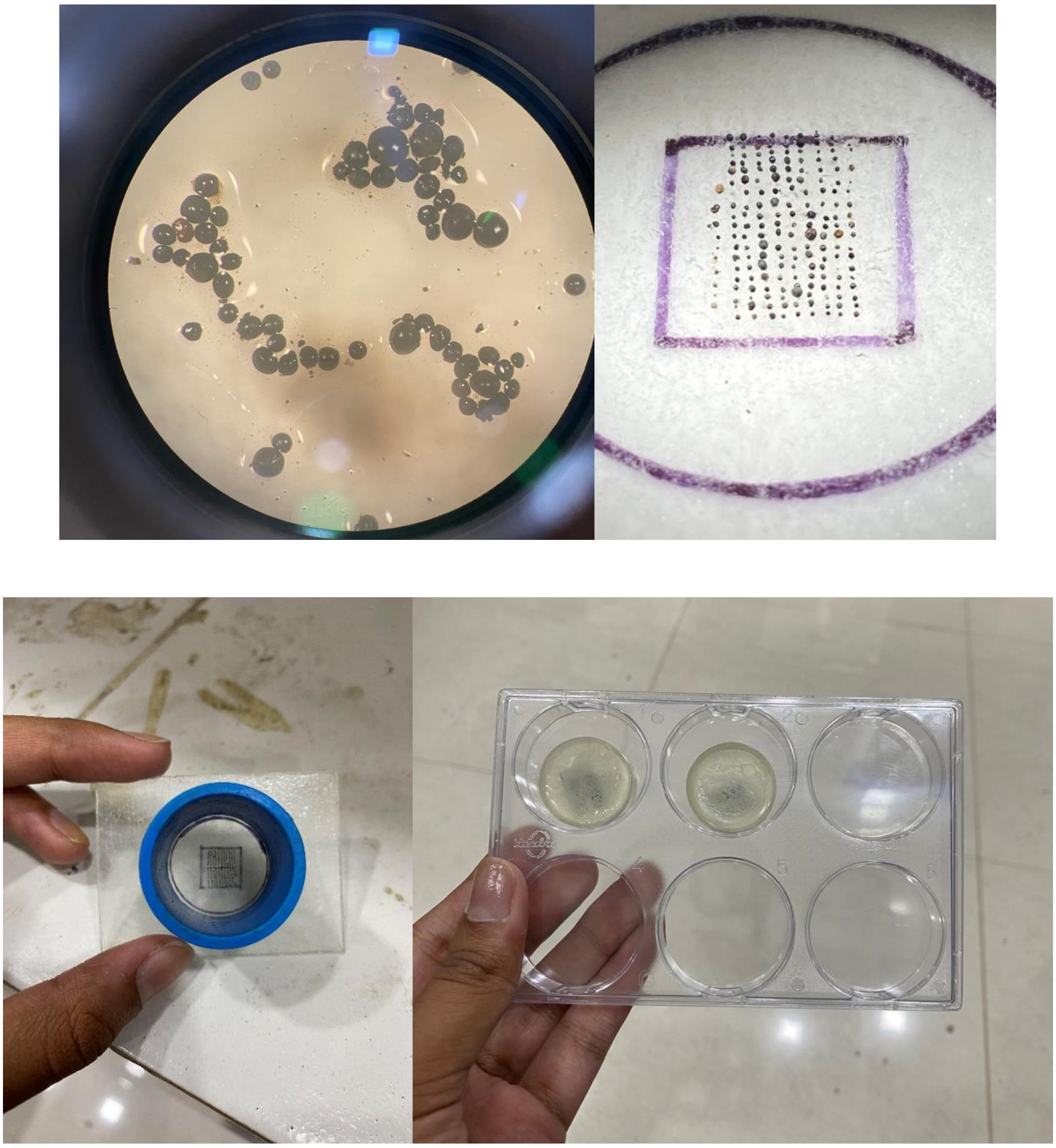

Figure 3.2: Some steps involved during the picking of potential particles, mounting and preparation of epoxy mounts.

CHAPTER – 4

RESULTS

4.1. RESULTS

The samples MS-I6, MS-I7, and MS-I35 were collected from Maitri Station in Antarctica. Sieving and magnetic separation of the samples was done after which potential particles were picked from the samples. The micrometeorite samples were then mounted and polished. These mounted samples were then labelled and marked. Once labelled and marked, ultrasonic cleaning is done followed by carbon coating of the sample. Finally, the textural analysis is carried out with the help of SEM.

The following results were obtained from the SEM:

4.1. Sample MS-I6:

Table 4.1: Sample MS-I6 data showing the number of MMs, percentage (%) of MMs, and etching % of MMs.

SAMPLE MS-I6			
Type of MMs	**Number of MMs**	**Percentage (%) of MMs**	**Etching %**
Barred Olivine	68	39	3.9
Porphyritic	77	44.2	6.0
Cryptocrystalline	8	4.5	3.5
Glassy	3	1.7	3.4
Scoriaceous	4	2.2	7.0
G-Type	2	1.1	8.3
I-Type	12	6.8	4.3
Total	174	100	100

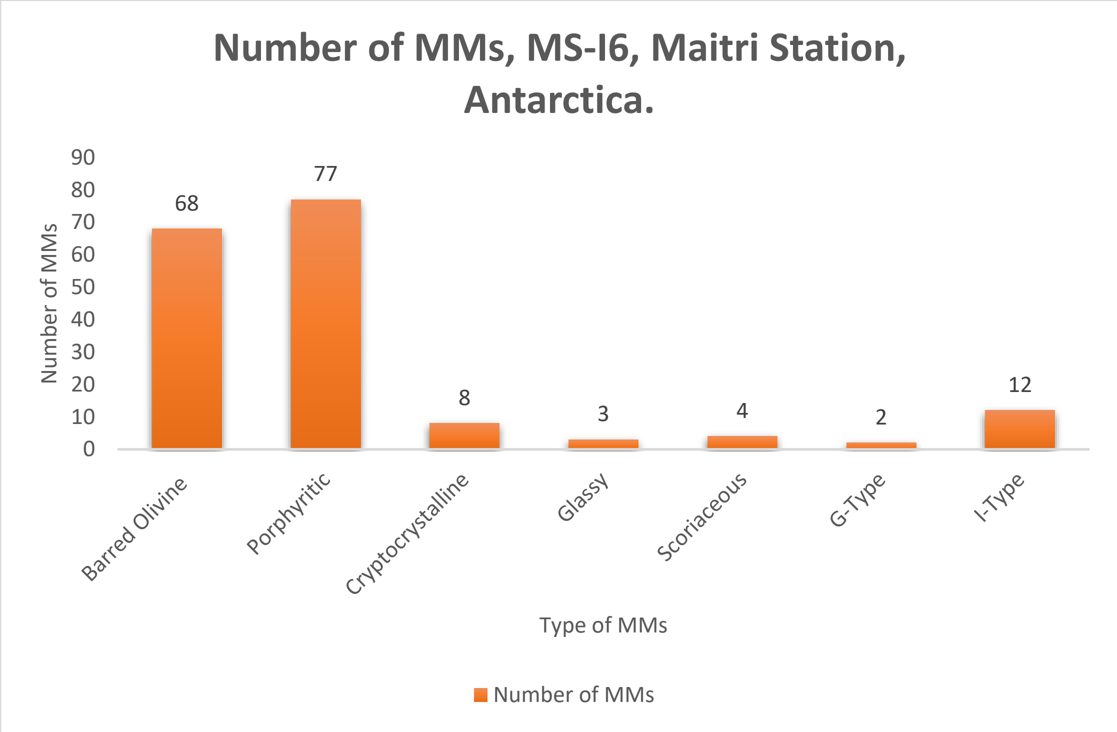

Figure 4.1: Number of MMs in sample MS-I6, Maitri Station, Antarctica.

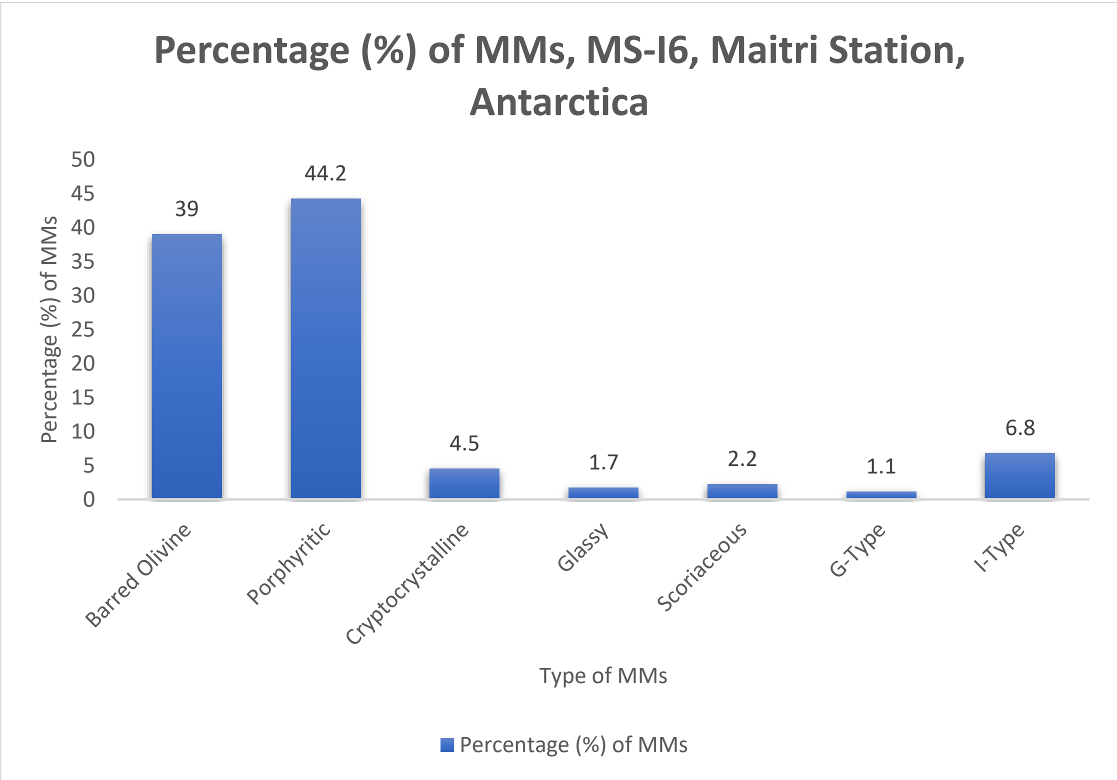

Figure 4.2: Percentage (%) of MMs in sample MS-I6, Maitri Station, Antarctica.

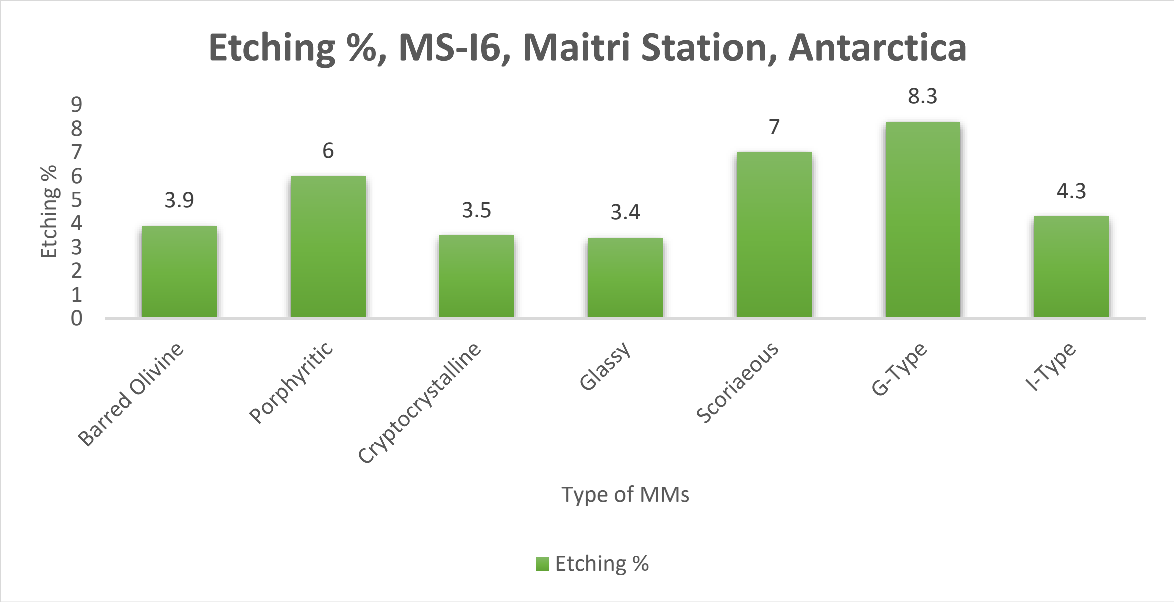

Figure 4.3: Etching (%) of MMs in sample MS-I6, Maitri Station, Antarctica.

4.2. Sample MS-I7:

Table 4.2: Sample MS-I7 data showing the number of MMs, percentage (%) of MMs, and etching % of MMs.

SAMPLE MS-I7			
Type of MMs	**Number of MMs**	**Percentage (%) of MMs**	**Etching %**
Barred Olivine	42	22.7	3.3
Porphyritic	90	48.6	4.7
Cryptocrystalline	13	7	3.6
Glassy	16	8.6	3.0
Scoriaceous	1	0.5	4.9
G-Type	9	4.5	4.2
I-Type	14	7.5	3.7
Total	185	100	100

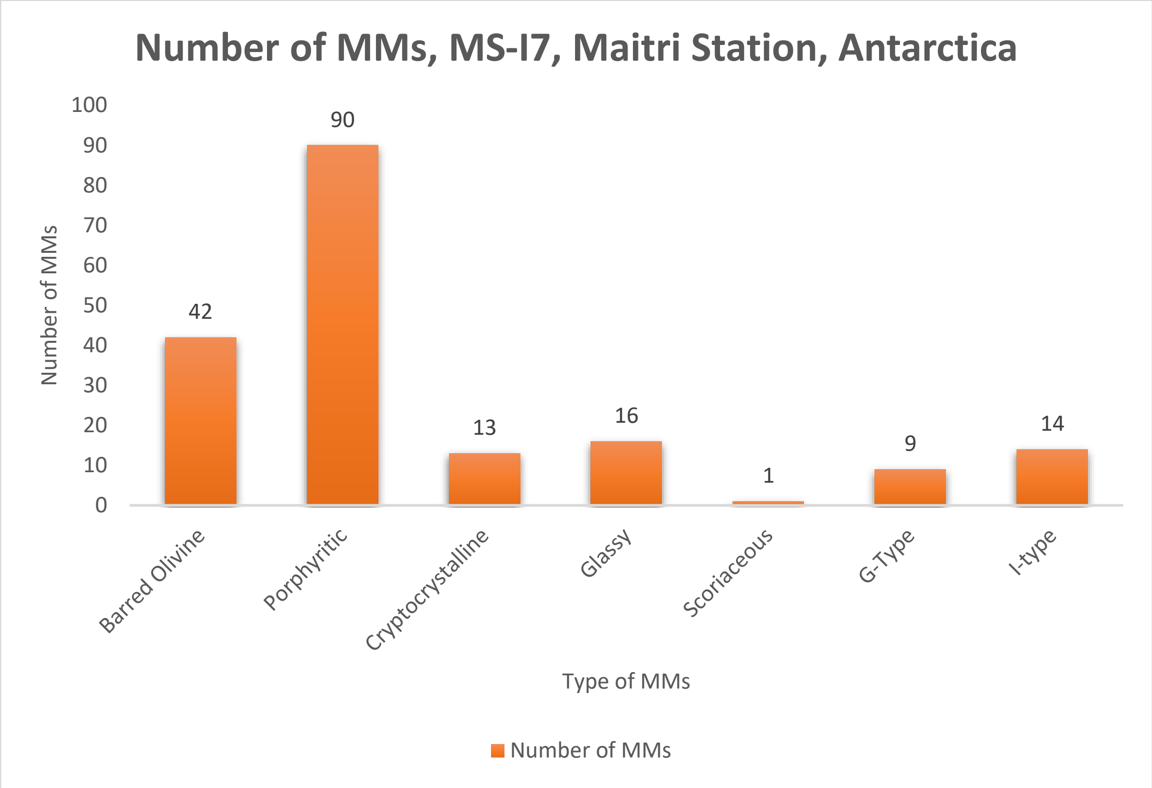

Figure 4.4: Number of MMs in sample MS-I7, Maitri Station, Antarctica.

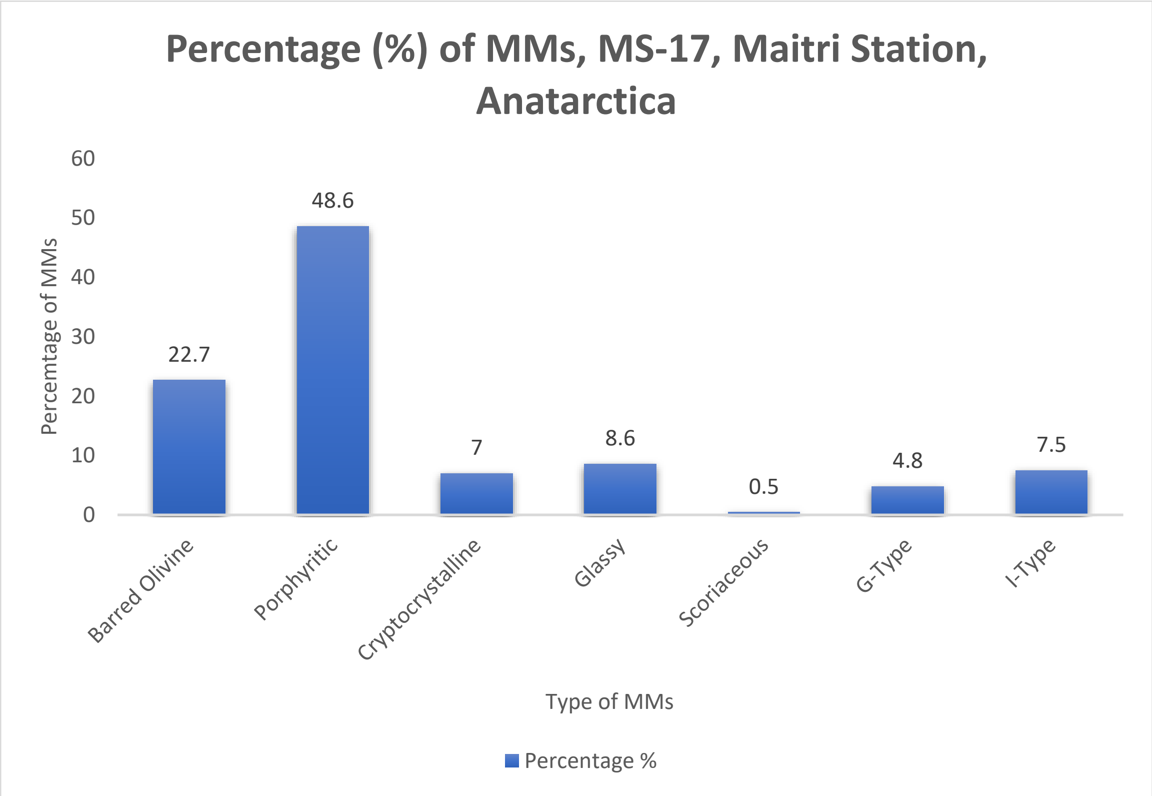

Figure 4.5: Percentage (%) of MMs in sample MS-I7, Maitri Station, Antarctica.

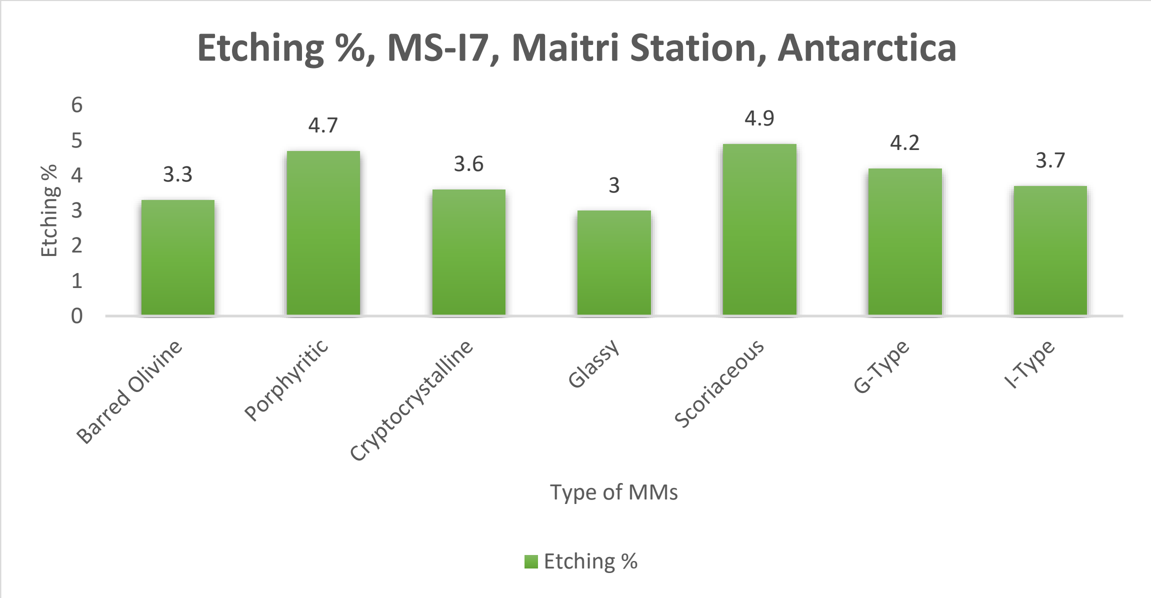

Figure 4.6: Etching (%) of MMs in sample MS-I7, Maitri Station, Antarctica.

4.3. Sample MS-I35:

Table 4.3: Sample MS-I35 data showing the number of MMs, percentage (%) of MMs, and etching % of MMs.

SAMPLE MS-I35			
Type of MMs	**Number of MMs**	**Percentage (%) of MMs**	**Etching %**
Barred Olivine	48	7.9	4.2
Porphyritic	261	43.0	3.8
Cryptocrystalline	139	22.9	3.5
Glassy	63	10.4	3.4
Scoriaceous	26	4.3	5.0
G-Type	15	2.5	6.1
I-Type	55	9.1	3.4
Total	607	100	100

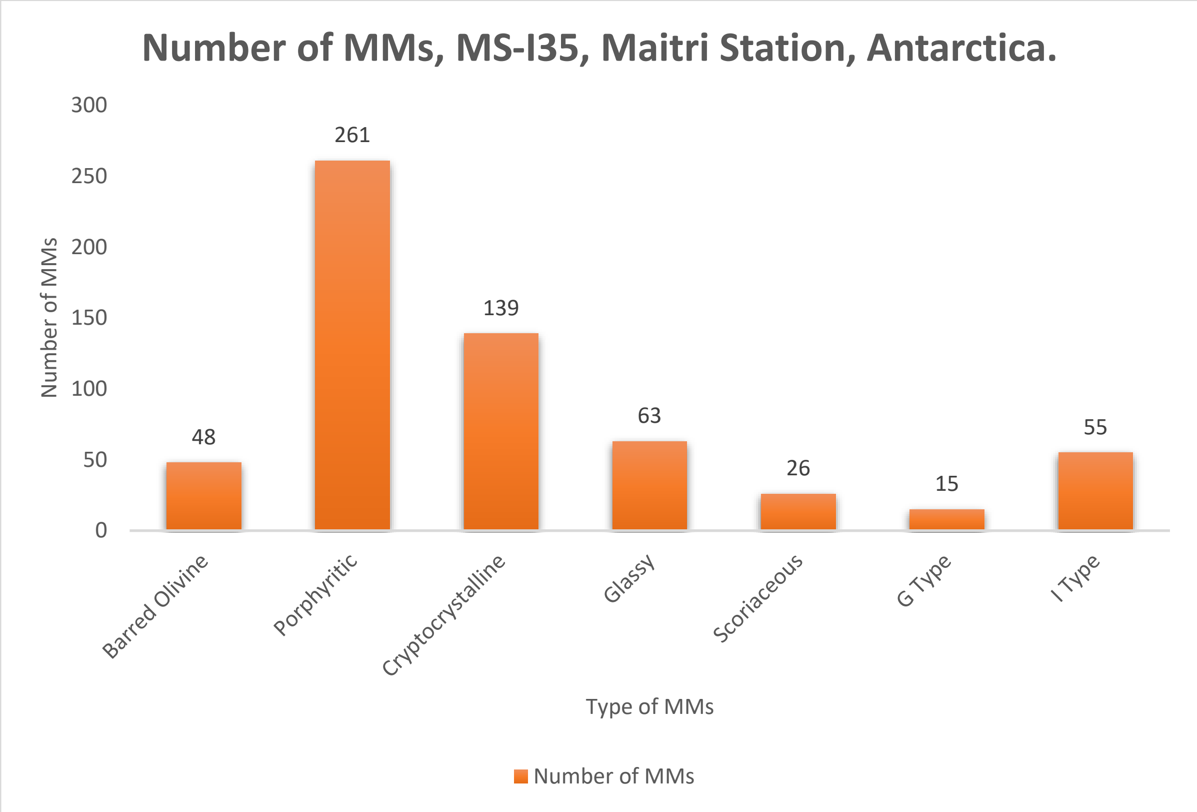

Figure 4.7: Number of MMs in sample MS-I35, Maitri Station, Antarctica.

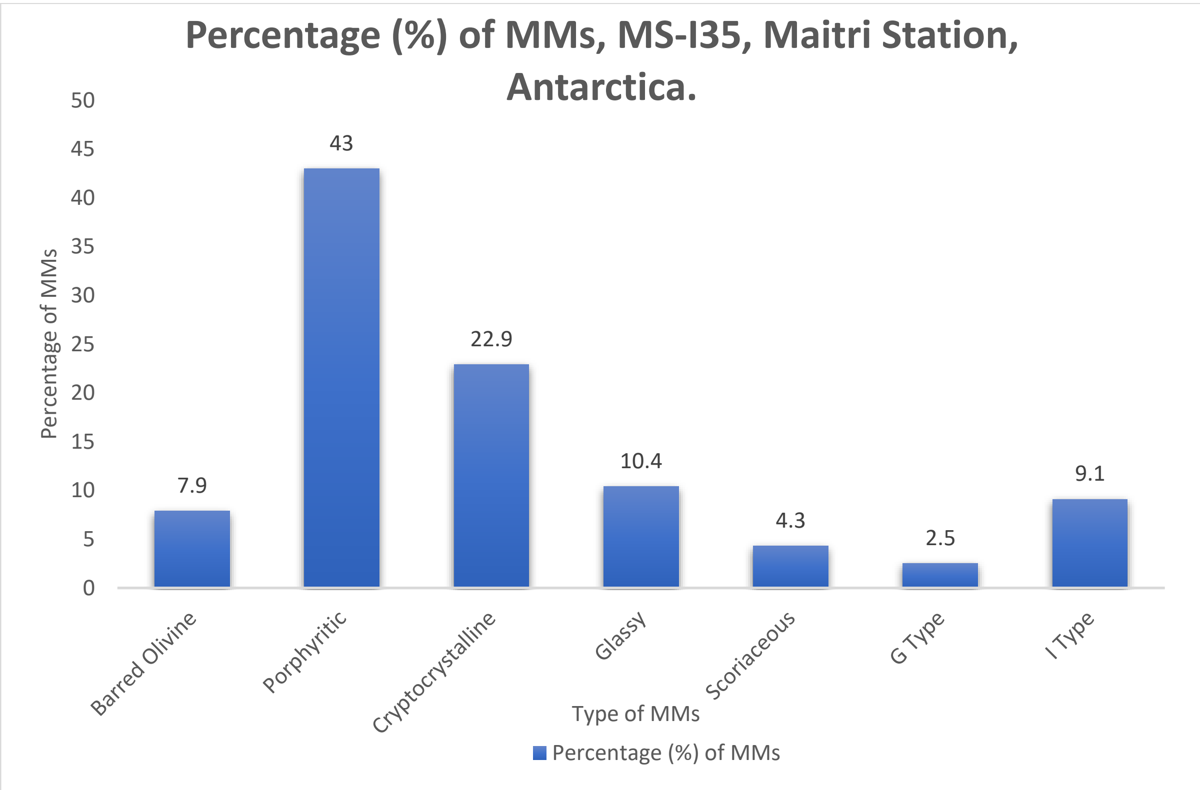

Figure 4.8: Percentage (%) of MMs in sample MS-I35, Maitri Station, Antarctica.

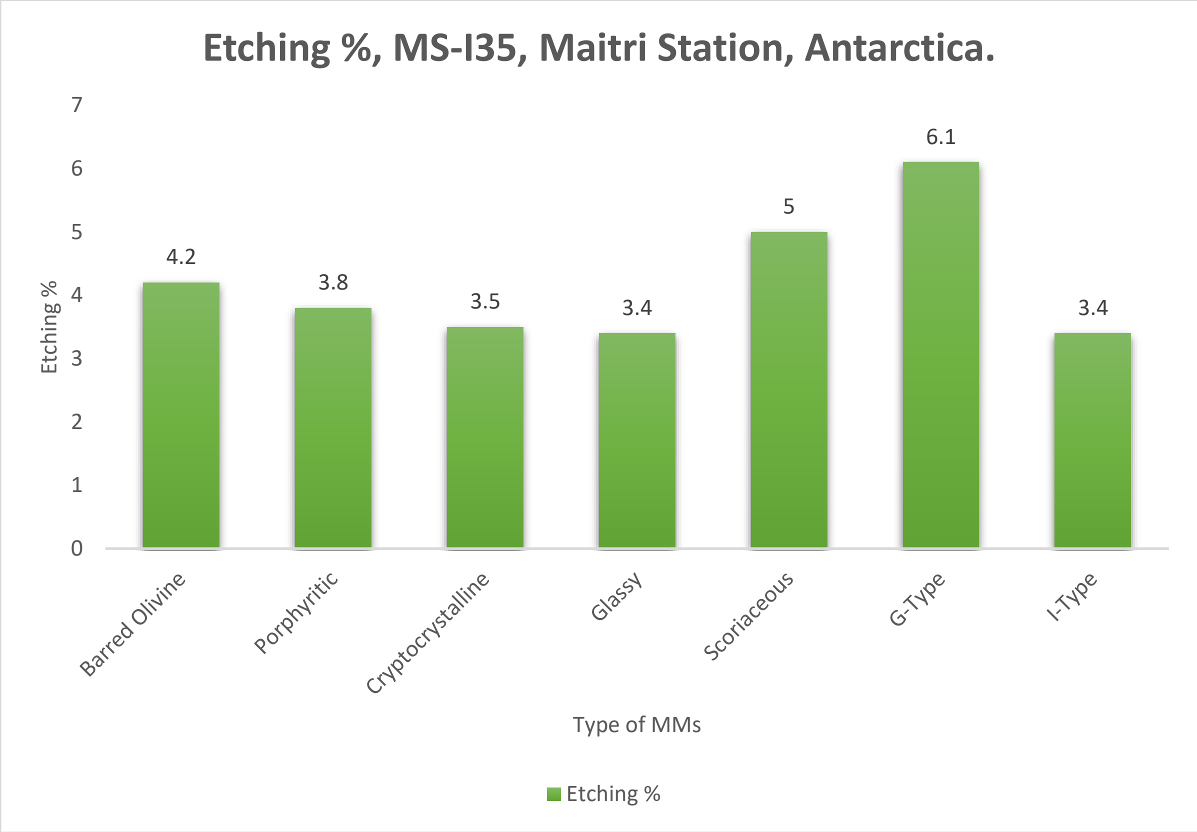

Figure 4.9: Etching (%) of MMs in sample MS-I35, Maitri Station, Antarctica.

CHAPTER – 5

DISCUSSION

5.1. Discussion

The current study is based on the extensive analysis of micrometeorite compositions across samples MS-I6, MS-I7, and MS-I35 revealing effective patterns. Porphyritic micrometeorites consistently show abundance, constituting a significant portion (roughly 44% to 49%) of the total recovered micrometeorites in each sample. Conversely, G-type meteorites consistently were the least common, making up a mere 1-5% of the total samples analysed.

The G-type meteorites exhibited a persistently higher average etching value across all three samples compared to the silicate-rich composition of porphyritic meteorites, signifying an enhanced susceptibility to the ravages of etching that has happened on the Earth’s surface. This dissimilarity can be attributed to their distinct compositional characteristic – primarily iron and nickel. G-type spherules have magnetite dendrites in the glassy groundmass. This glassy groundmass is susceptible to etching because of its small binding capacity and the dendrites present are enclosed in the glass, making the glass a weak plane which makes these spherules significantly more vulnerable to etching on Earth.

These observations strongly suggest a convincing correlation between a micrometeorite's composition and its susceptibility to etching on Earth’s surface.

Further research ventures could delve deeper into this intriguing relationship by analysing a broader and more diverse array of micrometeorite samples. This would not only solidify the current observations but also shed light on the etching behaviour of other micrometeorite types, potentially leading to the discovery of new compositional factors that influence susceptibility to space weathering and etching on Earth. Additionally, investigating the potential link between etching value and the origin or formation processes of meteorites could offer invaluable insights into their extraterrestrial history. By unravelling the secrets encoded within these etching values, scientists might be able to reconstruct the formation environments and cosmic journeys undertaken by these celestial visitors, providing a deeper understanding of the origins of our solar system and the potential existence of meteoroids elsewhere in the universe.

CHAPTER – 6

CONCLUSIONS

6.1. CONCLUSION

In **sample MS-I6**, out of a total of 174 meteorites identified, 77 were porphyritic, 68 were barred olivine, 12 were I-type, 8 were cryptocrystalline, 4 were scoriaceous, 3 were glass, and 2 were G-type textured.

Porphyritic MMs are the most common type, making up 44.2% of all MMs found. Their average etching value is 6%. In contrast, G-type MMs are the least common, accounting for only 1.1% of the total MMs. However, they have the highest average etching value, at 8.3%.

In **sample MS-I7**, among the 175 meteorites identified, 90 were porphyritic, 42 were barred olivine, 16 were glass, and so on. In total, there were 14 I-type, 13 cryptocrystalline, and 9 G-type textured MMs found.

Porphyritic MMs are the most abundant among MMs, constituting around 48.6% of all MMs. Their average etching value is around 4.7%. Conversely, G-type MMs are the rarest, accounting for only around 4.8% of MMs. However, they boast the highest average etching value, at 4.2%.

In **sample MS-I35**, a total of 607 MMs were identified out of which 261, 139, 63, 55, 48, and 15 were porphyritic, cryptocrystalline, glass, I-type, barred olivine, and G-type textured respectively.

Here, the porphyritic MMs are considerably high in number and are 43% of the total MMs found; with an average etching value of 3.8%. Whereas, G-type MMs are the least in number and are 2.5% of the total MMs found and have the highest average etching value of 6.1%.

The porphyritic MMs contain larger crystals embedded within a finer-grained matrix. Their composition can vary but they often contain less metal and more silicate minerals, which are generally more resistant to the etching effects that take place on Earth. The reason behind G-type MMs being more etched than porphyritic MMs is because of their differing compositions and susceptibility to chemical weathering on Earth. The G-type MMs are composed primarily of iron and nickel, similar to the metal found at the core of the planet and because of this metallic composition, they are more prone to corrosion by cosmic rays and solar wind particles they encounter in space and even on Earth, leading to a more etched surface. The susceptibility to etching is due to the difference in the materials present in each type of MM.

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