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A UNIQUE LOOK ON MICROMETEORITES: WHEN SPECTROSCOPY MEETS CITIZEN SCIENCE

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RESUMEN

Los micrometeoritos (MM) son partículas de polvo extraterrestre que sobreviven a la entrada atmosférica y pueden recuperarse de la superficie de un cuerpo planetario y, en términos de masa, constituyen una parte importante del flujo de material extraterrestre que se acumula en la superficie de la Tierra. Los MM que hemos analizado en este trabajo están compuestos de varios minerales, incluidos metales (como el níquel y el hierro) y silicatos (como el olivino y el piroxeno). Su composición y nivel de alteración pueden variar ampliamente dependiendo de su historia y a partir de su mineralogía y textura (relaciones espaciales y las formas de las fases dentro de las rocas) es posible obtener información sobre su alteración causada por los procesos de entrada atmosférica.

ABSTRACT

Micrometeorites (MMs) are extraterrestrial dust particles that endure atmospheric entry and are recoverable from the surface of a celestial body. In terms of mass, they constitute a significant portion of the extraterrestrial material flux accumulating on the Earth's surface. The MMs examined in this study consist of diverse minerals, encompassing metals such as nickel and iron, as well as silicates like olivine and pyroxene. Their composition and degree of alteration can vary widely, influenced by their unique history. The mineralogy and texture of MMs offer valuable insights into the alterations induced by atmospheric entry processes.

Key Words: instrumentation: spectroscopy — meteorites — methods: observational

1. INTRODUCTION

The extent of heating experienced by micrometeoroids entering Earth's atmosphere varies depending on factors such as size, mass, entry velocity, and angle. This results in flash melting and a diverse array of quench textures, morphologies, and chemical compositions. Combining these textures and chemical compositions enables the standardization of micrometeorite classification (Genge et al. 2008, Rubin & Grossman 2010). Micrometeorites (MMs) complement observations of meteor phenomena (Silber et al. 2018, Moilanen, Gritsevich & Lyytinen 2021), offering precise mineral and compositional determinations through laboratory techniques. This, in turn, provides essential constraints for interpreting spectroscopic data obtained from astronomical observations.

Collecting and identifying MMs need a deep understanding of what to seek and what to discard. Earlier research in this field, from NASA's comparative analysis of cosmic and industrial spherules in the 1960s to contemporary investigations into road dust in India and Hungary, has been fragmented and generally concluded that isolating micrometeorites in populated areas is a formidable challenge (Kurat et al. 1994). Therefore, MMs samples of the extraterrestrial dust flux allow study of the dust population within the early solar system and the nature and evolution of their parent bodies. The preservation of such particles in sediments also provides a record of events occurring beyond our planet over geological time (Dredge et al. 2010).

2. MICROMETEORITE SAMPLES AND INSTRUMENTATION

In 2010, Jon Larsen embarked on a systematic exploration of dust samples from populated areas. Beginning with surfaces oriented skywards, such as roads, roofs, parking lots, and industrial zones, where particles could accumulate over time, Larsen expanded his search to encompass diverse environments around the world, including cities, countries,

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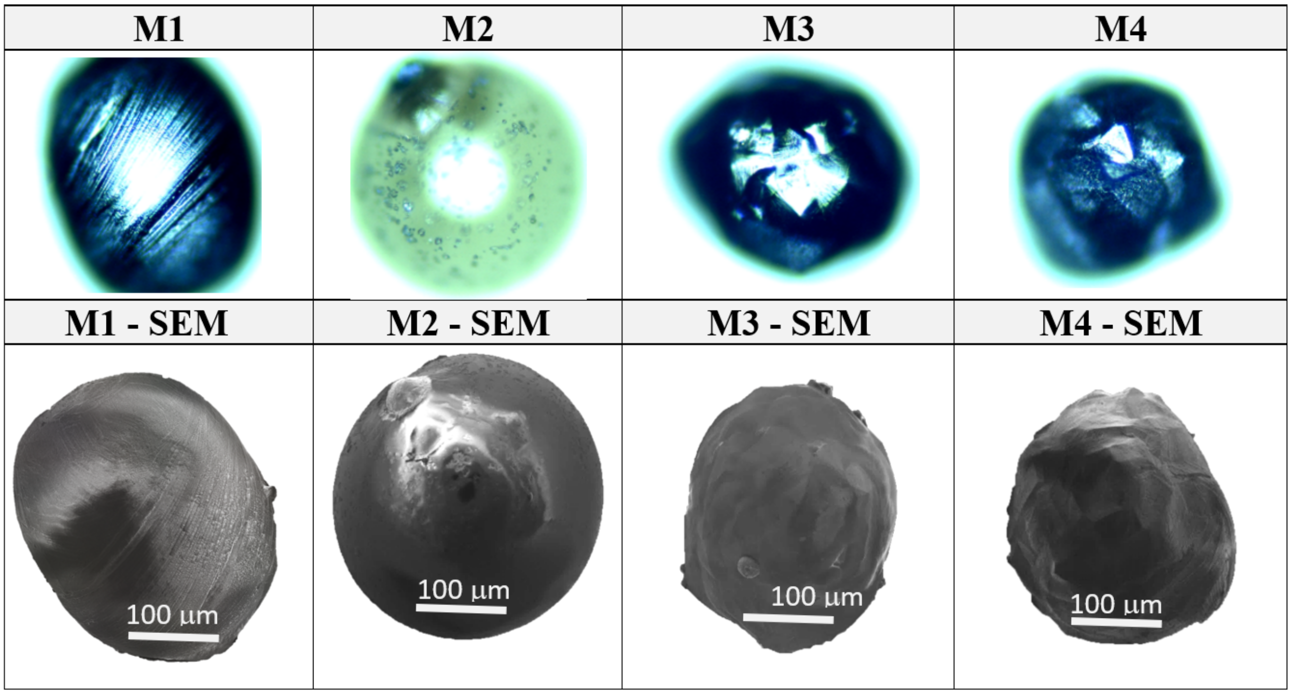

Fig. 1. Optical and scanning electron microscope (SEM) images of the MMs samples studied in this work.

mountains, beaches, and deserts. Now, after over a decade of research, spanning around 50 countries and involving over 1,000 field searches, representatives from every continent, he has amassed a substantial collection. Figure 1 shows the four selected MMs samples (named here M1-M4) from the Jon Larsen collection (Larsen 2017).

We have studied them by scanning electron and Raman microscopies. The scanning electron microscope (SEM) images were acquired by a high-performance scanning electron microscope with a high resolution of 3.0 nm, JEOL JSM-6490LV microscope. The Raman spectra were acquired with an Invia Qontor Confocal Raman microscope with and excitation laser of 532 nm. Its resolution was set at 2 cm^{-1} and the geometry of micro-Raman measurements was 180°. Laser focus diameter, which was of ca. 12 μm, allows measurements on a micrometer scale.

3. RESULTS AND ANALYSIS

The classification of micrometeorites depends on the peak temperature reached during atmospheric entry, caused by frictional heat that induces significant variations in the alteration process. About half of the micrometeoroids with sizes <0.1 mm experience a soft deceleration, ending up on the ground as unmelted MMs. The other half reaches peak temperatures between 1350−2000°C, sufficient to generate various types of melted cosmic spherules through the quenching process during atmospheric flight (Genge et al. 2008, Rubin & Grossman 2010).

The MMs examined in this study belong to the S-type group, which is the most common, characterized by olivine microphenocrysts, silicate glass, and often containing magnetite and/or chromite.

Within this S-type, they can be further subdivided into several subclasses based on their textural and mineralogical characteristics (Genge et al. 2008). In this work, we studied four MMs from three different subclasses: barred olivine spherules dominated by parallel growth dendrites of olivine (Fig. 1, M1), glass (V-type) vesicular spherules featuring a nickel-iron bead (Fig. 1, M2), and cryptocrystalline spherules (Fig. 1, M3 and M4).

We observe that **M1** sample is an aerodynamic ellipsoid micrometeorite that features a dark gray body color and fascinating circular crystal formations on its surface. Raman spectra on sample **M1** (Fig. 2) show distinctive bands of forsterite type olivine recorded at 821 and 853 cm^{-1} with magnetite Raman main band at 679 cm^{-1}. Dark olivine plate crystals interposed by interstitial magnetite crystals that glimmer in the light characterize the body of **M1**.

The sample **M2** is a glass (V-type) vesicular spherule that features a nickel-iron bead. We have acquired the corresponding Raman spectra in the

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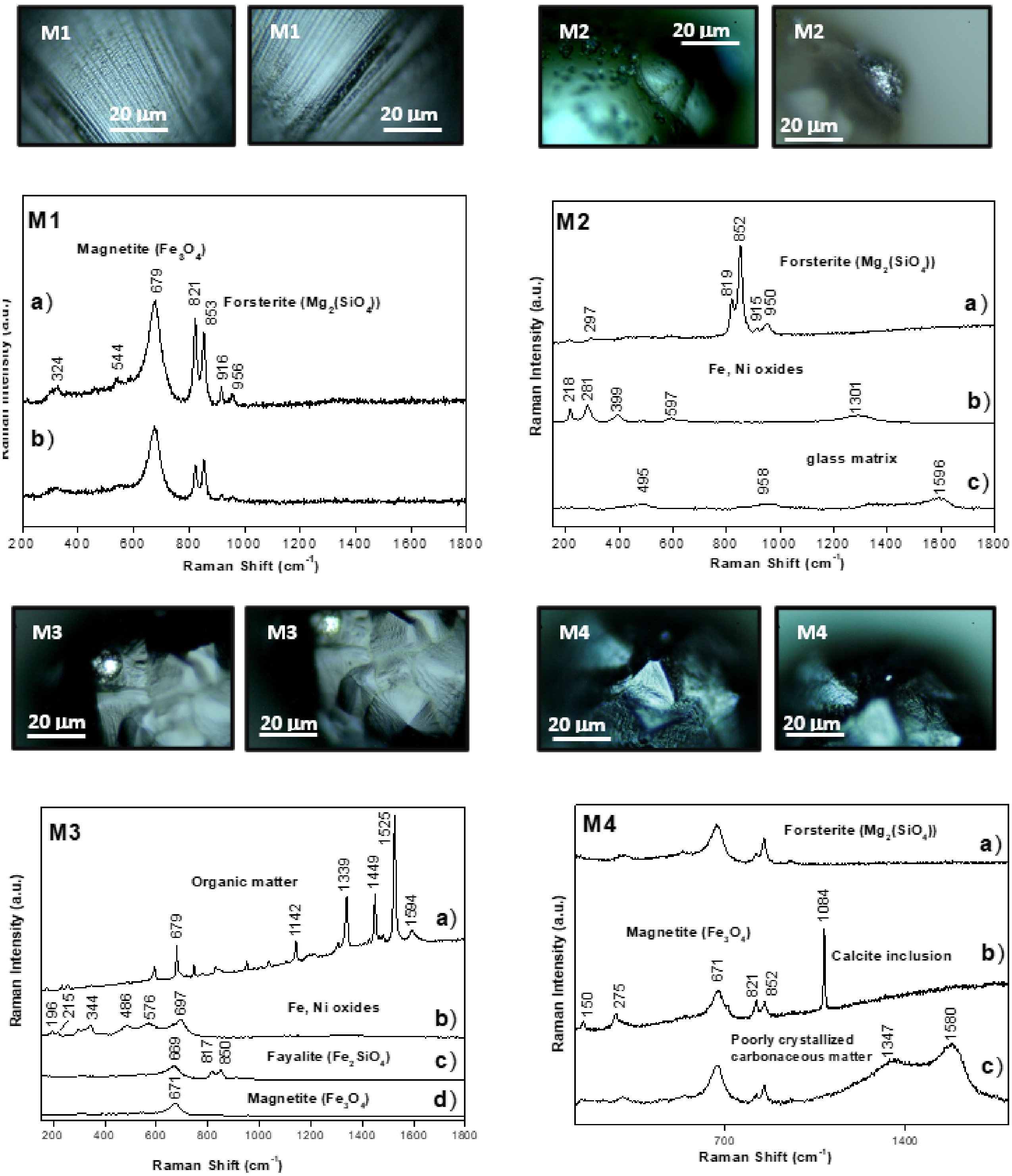

Fig. 2. Raman spectra of MMs studied and optical images (50x objective) showing details of the samples around the recorded area.

bead (Fig. 2, M2b) and in the area around it concluding that there are blends layers of olivine crystals (Fig. 2, M2a) on top of its main glass body (Fig. 2, M2c).

The **M3** sample is a cryptocrystalline spherules dominated by radiating clusters of fine olivine dendrites. In this case we observe that the Raman olivines bands recorder at 817 and 850 cm-1 (Fig. 2, M3c) are wider than the one in Fig. 2, M1a because the Raman spectrum of fayalite, Fe_2SiO_4, is different in appearance from the spectra of other isostructural olivine as i.e. forsterite, Mg_2SiO_4. For example, at ambient temperature the line width FWHH of the mode at 817 cm^{-1} could be about 1.5 times and the mode at 850 cm^{-1} about 3.5 times larger than the equivalent modes in forsterite. This broadening could be related to Fe^{2+} and its magnetic properties in the olivine structure (Kolesov & Geiger 2004). **M3** sample exhibits a nickel-iron bead in which we have detected organic compounds. Fig. 2, M3a shows that besides the weaker signal of olivine the spectrum presented several bands in the typical organic compounds' region of 1050−1650 cm^{-1}.

The **M4** micrometeorite sample is another cryptocrystalline spherule dominated by phenocrysts of forsterite type olivine (Fig. 2, M4a). We have detected a very strong Raman band at 1084 cm^{-1} corresponding to a calcite inclusion within the olivine matrix. We can observe in Fig. 2, M4c Raman bands of carbonaceous D and G bands, recorded at approximately 1347 cm^{-1} and 1580 cm^{-1}, respectively. These bands reflect the highly disordered carbonaceous phases present in **M4** micrometeorite.

4. CONCLUSIONS

Scanning electron microscopy has been employed to examine the morphology of four selected micrometeorites from the Jon Larsen Collection. MicroRaman spectroscopy was utilized as an appropriate tool to study the chemical composition of these samples, known for their heterogeneous minerals. We identified two isostructural olivines, forsterite and fayalite, along with metal phases and carbonaceous material.

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