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Diatoms in the Orgueil Meteorite

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Abstract—We report the discovery of frustules of pennate diatoms embedded in a freshly fractured interior surface of the Orgueil CI1 carbonaceous meteorite. Images and element composition by Energy Dispersive X-ray Spectroscopy were obtained with the TESCAN VEGA 3 Scanning Electron Microscope (SEM) in the Astrobiology Sector of the Laboratory of Radiation Biology of the Joint Institute for Nuclear Research in Dubna, Russia. The distribution of chemical elements as shown by Energy Dispersive X-Ray Spectroscopy (EDS) and 2-D element maps show no detectable nitrogen. Hence the diatoms are interpreted as indigenous to the Orgueil meteorite and therefore have direct implications to the existence of extraterrestrial life; and the hypothesis of Panspermia.

Keywords: diatoms, Orgueil, meteorite

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INTRODUCTION

The Orgueil meteorite is the most extensively investigated of all of nine CI1 chondrites known on Earth. The fall occurred in southern France on May 14, 1864. Many jet-black stones fell within a 15 km EW scatter-ellipse around the village of Orgueil (43°54′ N; 01°24′ E). Contemporaneous letters describing the fireball path, physical appearance and properties of the stones were quickly published (Nagy, 1975). The atmospheric trajectory and orbital parameters computed from these eyewitness reports indicate the orbital plane was close to the ecliptic; pre-atmospheric velocity >17.8 km/s; aphelion >5.2 AU (semi-major axis of Jupiter orbit) and the perihelion (~0.87 AU) was inside the Earth's orbit. These calculations indicated the most probable parent body of the Orgueil meteorite was one of the Jupiter-family of comets but the Halley-type comets (aphelia >38 AU) could not be excluded (Gounelle et al., 2006). The Orgueil stones were analyzed immediately after the fall at the Académie des Sciences. Pisani (1864) found the Orgueil meteorite contained carbon, water, magnetite, silicic acid, clay minerals, serpentine and a complex polymeric carbonaceous material that was insoluble in water and similar to humic substances, peat and coal. Cloëz (1864) reported indigenous hygroscopic water (5.2–6.9%) and water of hydration (8–10%) liberated only above 200°C, chlorite and other phyllosilicate clays and evaporite minerals Epsomite ($MgSO_4 \cdot 7H_2O$) and Gypsum ($CaSO_4 \cdot nH_2O$). Leymerie (1864) sliced open a freshly fallen Orgueil stone and described the interior: "The broken surface reveals a dark charcoal colored substance so soft that it can be easily cut with a knife. One can even write with the fragments on a piece of paper. The knife cut creates a smooth and shiny surface which is an indication of fine, paste-like matter. Fragments placed in water disintegrate immediately." These observations were strikingly similar those of the French chemist Thénard (1806) who studied the Alais CI meteorite immediately after the 1806 fall.

He found the Alais stones to be different from all other meteorites as they resembled solidified clay "when the stones were placed in water they disintegrated immediately and gave off a strong clay-like odor." Berzelius (1834) almost threw his sample away when he discovered it contained water as thought it was contaminated. He then learned the Alais meteorite stones were like wet clay when they arrived on Earth.

This astonishing property of the Alais and Orgueil meteorites to disintegrate immediately when placed in liquid water is because the stones are a micro-regolith breccia cemented together by water-soluble salts.

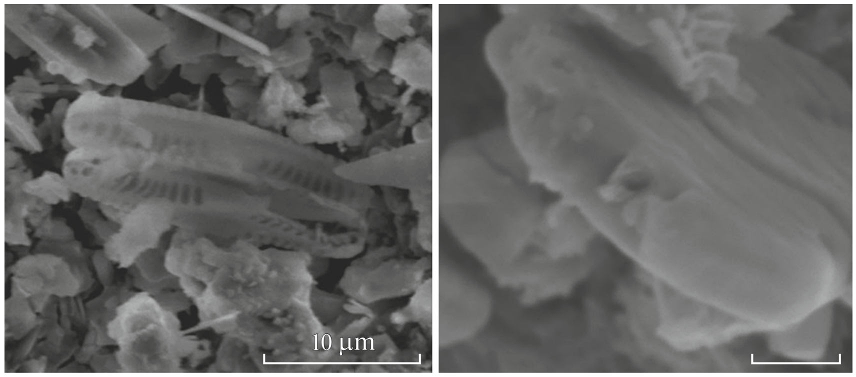

Fig. 1. SEM image of (a) two pennate diatoms and (b) SEM image of small diatom in the Orgueil meteorite (length of the scale bar is 1 μm).

Fine-grained phyllosilicates are sparsely distributed throughout the black rock matrix as tiny fragments and crystals of olivine, pyroxene, elemental iron, presolar diamonds, graphite and an insoluble organic matter similar to coal or kerogen (Boström and Fredrickson, 1966). The CI1 meteorites are distinguished from all other carbonaceous chondrites by a complete absence of chondrules and refractory inclusions and by their high abundance of pre-solar grains and high degree (~20%) of indigenous water of hydration (Tomeoka and Buseck, 1988; Endress and Bischoff, 1993, 1996). The microscopic particulates in the Orgueil clays became solidly cemented together when extraterrestrial water in the Orgueil stones evaporated after arrival on Earth causing precipitation of the water soluble salts. The presence of small veins of preterrestrial magnesium sulfate was noticed; either as epsomite ($MgSO_4 \cdot 7H_2O$) or hexahydrite ($MgSO_4 \cdot 6H_2O$) (Gounelle et al., 2006). Studies by SEM and EDS at the NASA/MSFC found hollow sheaths of cyanobacterial filaments were infilled with magnesium sulfate, that was possibly introduced when saturated water flowing in the parent body entered the sheaths after death of the organisms (Hoover, 2005).

MATERIALS AND METHODS

The Orgueil sample used in this study was fractured from a 0.3 g fragment of the Orgueil meteorite (MNHNP #2838) provided to Hoover for scientific research by Dr. Claude Perron and Dr. Martine Rossignol-Strick of Musée Nationale d'Histoire Naturelle de Paris. After transfer to the NASA/Marshall Space Flight Center it has been stored in a sealed vial and maintained in a freezer. On April 28, 2017, a fragment was removed from the vial and prepared for Electron Microscopy studies at NASA/MSFC. The fragment was fractured using flame sterilized tools and mounted on an SEM stub using the protocols and methods described by Hoover (Hoover, 2006, 2011). This freshly fractured uncoated sample of the Orgueil carbonaceous meteorite was designated "Org_2838_A1". It was studied at NASA/MSFC in Huntsville, Alabama with the FEI Quanta 600 Field Emission Gun SEM. The SEM stub was removed and transported to Russia for study with the new TESCAN VEGA 3 SEM of the Astrobiology Sector, Laboratory of Radiation Biology at the JINR in Dubna.

RESULTS

Complete frustules of fossil diatoms were discovered in sample "Org_2838_A1" in Dubna (Fig. 1a). Calibrated measurements of the Orgueil diatoms show the cells have lengths of 20.1 μm (upper) and 19.6 μm (lower). The cells are about 4–5 μm broad but tilt of cells prevent precise measurements. Energy Dispersive X-Ray Spectra and 2-D Element X-ray maps did not detect nitrogen indicating it was below the 0.5% detection limit and 2-D X-ray maps indicate the Orgueil diatoms are coated with sulfates of calcium and magnesium. The valves of the Orgueil diatoms are linear-lanceolate with rounded apices and there is a broad transverse facia in the central area. Raphe details of the Orgueil diatoms are not discernable. The Orgueil diatoms have about 15 transapical striae per 10 μm and the striae are radiate towards the middle of the valve and convergent toward the apices.

A small (~7 × 3 μm) pennate diatom was found in the sample "OR_7/2004_PSF1-RBH" (Fig. 1b). The frustule is encrusted with magnesium sulfate. The coating precludes determination of striae and raphe details.

CONCLUSIONS

Well-preserved cyanobacterial filaments, prasinophytes and other microfossils have been found in the Orgueil, Ivuna and Murchison meteorites during studies carried out since 1997 at the Borissiak Paleontological Institute, Russian Academy of Sciences in Moscow and at the NASA/Marshall Space Flight Center (Hoover, 1997; Zhmur et al., 1997; Rozanov et al., 2002; Hoover and Rozanov, 2003; Hoover et al., 2004; Rozanov, 2009a, 2009b). Diatoms were first discovered in the Orgueil meteorite in the Astrobiology Sector at the Laboratory of Radiation Biology of JINR in Dubna, Russia. Experiments at the NASA Marshall Space Flight Center in 2005 confirmed the 1864 reports that the Orgueil stones disintegrate when placed in water. The fact that the Orgueil stones would not have remained intact if they had landed in a body of liquid water provides evidence they were not invaded by diatoms or other aquatic algae after they arrived on Earth (Hoover, 2011). Water is absolutely essential for all known life forms and it is well-known that water and water-ice represents the dominant volatile of comets. There is also evidence that complex organics are present on comets and that liquid water can exist in cometary nuclei (Campins and Swindle, 1998; Lodders and Osborne, 1999; Podolak and Prialnik, 2000; Ehrenfreund et al., 2001). Diatoms are the dominant eukaryotic life form of the sea ice and polar caps of Earth and specialized proteins and morphological adaptations can allow them to live on and in the ice (Ligowski et al., 2012). These considerations led Hoover et al. (Hoover et al., 1986; Rozanov, 2009b) to suggest that communities of cold adapted diatoms, cyanobacteria and other photosynthetic microorganisms might be able to live on icy moons or in subcrustal ices and meltwater pools of comets. Nitrogen is present in all living and recently dead organisms at levels (2 to 20%) that are detectable by EDS. The EDS analysis and 2D X-ray Element maps failure to detect nitrogen and carbon indicates the diatoms in the Orgueil meteorite are fossils. The 2D Element maps also show that the Orgueil diatoms and surrounding regions of the Orgueil rock matrix are coated with precipitates of magnesium sulfate and calcium sulfate that could not have logically occurred post-arrival. Therefore, the Orgueil diatoms are interpreted as indigenous ancient microfossils rather than modern bio-contaminants. Microorganisms could be delivered to Earth by comets (Cometary Panspermia Hypothesis) (Hoyle and Wickramasinghe, 1981).

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