

TERRESTRIAL WEATHERING OF CHONDRITES IN NATURE AND CONTINUING DURING LABORATORY STORAGE AND PROCESSING: REVIEW AND IMPLICATIONS FOR SAMPLE INTEGRITY. Michael A. Velbel, Department of Geological Sciences, 206 Natural Science Building, Michigan State University, East Lansing, MI, 48824-1115 (velbel@msu.edu).

Introduction: Meteorites are naturally delivered samples from a variety of parent bodies throughout the solar system. Soluble mineral products of aqueous alteration and organic-chemical compounds occur in some chondritic meteorites and provide evidence for various aspects of the presence and nature of water and possible prebiotic chemistry at different episodes in Solar System evolution. However, these same minerals are highly vulnerable to modifying processes upon arrival at Earth. Some are so reactive in the presence of water (even as vapor) that even exposure to water in ostensibly dry environments (including laboratory atmosphere) results in elemental mobilization and formation of secondary minerals (usually evaporites) [1-11].

Chondrites, from small primitive, undifferentiated asteroidal parent bodies, have been shown to have been affected by redistribution of soluble minerals after recovery, during curatorial storage and processing. Proper planning for sample integrity and proper anticipation of the effects of inevitable exposure to Earth's atmosphere during storage and examination in terrestrial analytical laboratories both require thorough understanding of how minerals like those expected in returned samples from primitive small bodies react with terrestrial moisture and oxidants. This presentation reviews published accounts of the response of chondritic minerals to the moisture and oxidants in the terrestrial environment, and briefly explores their implications for sample return.

Terrestrial weathering of ordinary chondrites:

Natural. Terrestrial weathering of ordinary chondrites (OCs) is a natural experiment on how OC minerals respond to low-temperature, low-water-rock-ratio aqueous alteration. Oxidation of Fe in metal, sulfides, and ferrous silicates is ubiquitous in naturally weathered OC finds [1-6], in falls subjected to even a few decades of hot-desert weathering [6], and in OC falls recovered and curated promptly after recovery [6]. Slow hydrolytic weathering of primary OC silicates (olivine, pyroxene) concurrent with rapid Fe oxidation in metal and troilite liberates Mg, Ca, and Si [6,7]. Some Mg, Ca, and Si liberated from OC silicates by weathering are incorporated into "rusty" and silicate-mineral products [1-6] and / or mobilized and incorporated into sulfate and carbonate products of weathering [3,7-10]. Some Mg, Ca, and Si liberated

from OC silicates by weathering are lost (leached away) during terrestrial weathering of ordinary chondrites [6].

Post-recovery, laboratory processing and storage.

All oxidation, hydrolysis, hydration, and product-forming phenomena documented to affect OC finds in nature have been documented to continue in OC samples during processing, storage and examination in curatorial and laboratory settings, producing mineralogical and textural effects at scales of tens of microns easily discernable at TEM and even SEM magnifications on timescales of decades or less [6]. For example, modification of the OC find LEW 85320 has been shown to involve hydrolysis of olivine and formation of products, which are identical whether formed during natural terrestrial exposure or continued reaction during curatorial storage under N₂ atmosphere after recovery in Antarctica [7,8]. Environmental control lapses during sample storage have been shown to exacerbate some of these effects [10].

Evaporite minerals in and on carbonaceous chondrites: Carbonaceous chondrites are especially vulnerable to elemental mobilization and formation of secondary minerals (usually evaporites) during exposure to water in ostensibly dry environments (Antarctic cold deserts; laboratory atmosphere) [9-12]. Weathering in the curatorial and / or laboratory environment has been documented for falls of several C chondrite groups. Reactive soluble species (sulfates) were remobilized, apparently by exposure to moisture in laboratory atmosphere, during curatorial storage of the CI carbonaceous chondrite Orgueil [12]. Carbonate minerals have been similarly redistributed during storage of Vigarano (CV3) [13]. A strong correlation exists between the Mineralogical Alteration Index (MAI) [14] for non-Antarctic CM chondrite falls and the year of the fall – the longer ago the fall, the higher the MAI [15]. MAI has recently been shown to vary with the Chemical Index of Alteration, a widely used chemical-weathering index [11]. This suggests that MAI varies with terrestrial weathering of CM chondrites, even falls weathered after recovery and during storage [11].

Organic-clay interactions in carbonaceous chondrites: The search for organic carbon compounds indigenous to the parent bodies of meteorites and intentionally returned samples from solar system objects is a high priority for planetary materials

research [16]. C2 carbonaceous chondrite falls with phyllosilicates in their matrices adsorbed volatile organic-carbon compounds from laboratory sample-storage materials within one day, between sample preparation and analysis [16]. Similar contamination affected identically processed serpentine, smectite, and silica gel, but no such contamination occurred in an identically processed phyllosilicate-free carbonaceous chondrite of a different compositional class [16]. Phyllosilicate minerals are expected to be among the possible host phases for organic-carbon compounds in samples to be returned by future sample return missions to carbonaceous-chondrite-like asteroids, but the same phyllosilicates will be attractive host phases for terrestrial contaminant organic-carbon compounds [11,16]. The same reactivity (due to high surface-area/volume ratio) that makes fine-grained minerals of carbonaceous chondrites the most promising recorders of parent-body alteration may also make the fines the parts most vulnerable to reactions with terrestrial moisture, oxidants, and contaminants, even in museum and laboratory settings.

Summary: Improved scientific understanding is expected to result from acquisition of samples directly from their parent bodies, without the intermediate mineral-modifying processes that affect meteorites during atmospheric entry, terrestrial weathering, and storage. However, intentionally returned samples containing water-soluble or redox-sensitive minerals and / or organic-chemical compounds will be just as vulnerable to post-acquisition modification of their indigenous inventory of such compounds by reactions with terrestrial moisture, oxidants, and contaminants as are meteorites. Redistribution of soluble minerals and their constituent elements and isotopes, and modification of organic-chemical compounds, complicate the interpretation of these minerals and molecules and their significance for pre-terrestrial phenomena.

Low-preservation potential aqueous alteration features (e.g., evaporite minerals in their indigenous hydration states) will not survive intentional excursions of T and relative humidity during thermal sterilization for planetary protection, or excursions in which environmental controls for the sample-return container and laboratory containment protocols are either limited by design or fail. Temperature, relative humidity, and redox conditions must be strictly controlled during sample return missions, continuing after sample return to include curation, storage, and examination, if preservation of soluble and hydrated minerals and / or organic molecules in their indigenous textures, distributions, associations, and hydration and oxidation states are goals of sample return. Experience

with chondrite falls suggests that special care will be required during and after preliminary examination and after distribution of returned small-body samples to investigator laboratories in order to ensure that sample integrity carefully preserved during sample acquisition and return is maintained after sample allocation and distribution.

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