TRACING ORGANIC CONTAMINATION FROM COLLECTION TO CURATION: BEST PRACTICES FOR THE RECOVERY AND CONTAMINATION MITIGATION OF METEORITES. L. D. Tunney[1], P. J. A. Hill[1], C. D. K. Herd[1], and R. W. Hilts[1,2], [1]Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada, Email: ltunney@ualberta.ca, [2]Department of Physical Sciences, MacEwan University, Edmonton, Alberta T5J 4S2, Canada.

Introduction: Organic matter analyses on extraterrestrial materials can provide a glimpse into the chemistry of the solar system, including processes in the interstellar medium, solar nebula, thermal and aqueous alteration on asteroidal parent bodies, and potentially inform origin of life discussions [1,2]. The ability to differentiate between a meteorite's intrinsic characteristics from those that result from alteration and contamination after landing on Earth is crucial in order to draw accurate conclusions about our solar system. Terrestrial contamination of astromaterials has been extensively researched, especially as it relates to samples returned from missions [3]; however, little work has been conducted to document the controls of contamination and create a "how-to" guide for the recovery, collection, and curation of meteorites.

Soluble organic compound analyses on meteorites, both old and freshly fallen, can inform how terrestrial contamination – especially organic and/or biologic – and alteration interact with the intrinsic properties of astromaterials. Here we summarize results of the soluble organic analyses on a variety of different meteorite specimens that have variable collection and curation conditions spanning a range of meteorite types. From this, we present a series of recommendations for the best practices in the recovery and curation of meteorites.

Materials and Methods: Work used to infer best practices can be found in publications [4], [5], and [6]. These studies included eighteen Buzzard Coulee specimens [4], five Aguas Zarcas specimens (four pre-rain, one post-rain) [5], two Tarda specimens, a sand sample from the Tarda strewn field [6], and three Bruderheim stones. In nearly all cases, specimens were processed in the University of Alberta Meteorite Curation Facility in a Class 1000 cleanroom by a mixture of the following: (1) The exteriors of the specimens were rinsed with HPLC grade dichloromethane (DCM), (2) Specimens were subsampled, powdered and extracted with DCM, and/or (3) DCM-leached powders were then extracted with hot ultrapure water and derivatized with MTBSTFA. All rinses and extractions were then evaporated to 0.5 mL and analyzed by gas chromatography – mass spectrometry (GC-MS) to determine the detectable DCM-soluble organic compounds present [7]. The GC-MS analysis was performed on an Agilent 5975C using a HP-5MS column (30 m length, 0.25 µm film thickness, 250 µm internal diameter) at MacEwan University. Detection was executed with an Agilent 5975C mass selective detector (MSD). Procedural blanks were processed with identical steps in all analyses to monitor potential contamination introduced during the rinse and extraction. All materials used in the subsampling, rinsing, and extraction processes were cleaned with ultrapure water and HPLC grade DCM, and if possible, were combusted at 450°C for >6 hours. DCM extractions of swabs from surfaces within the curation facility were also analyzed to characterize the base level of contamination. Using the criterion that carbonaceous chondrites have a common suite of compounds that are identified as intrinsic [8], we can distinguish between what is likely intrinsic to the meteorite or a result of contamination based on outliers from this common dataset.

Summary of Results: The soluble organic compound results suggest that specimens were readily contaminated, both in ordinary and carbonaceous chondrites alike. Our studies lead to several inferences, including:

a) There is a temperature dependency of organic contamination transfer to meteorites during curation, wherein colder storage temperatures hinder the accumulation of contaminants.
b) There is a time dependency of organic contamination wherein contaminants may either degrade or penetrate into the meteorite over time. The longer the time period between collection and analyses conducted, the fewer contaminants detected [4]. This trend has yet to be shown for intrinsic organics but there could be a loss of intrinsic compounds over time, in particular with volatile species.
c) The properties of the meteorite itself may impact the degree of contamination. Our study showed that the fusion crust may act as a barrier, whereas the exposed interiors of the meteorites are more abrasive and facilitated the accumulation of organics from materials in direct contact with the specimen.
d) The derivatization agent choice can greatly impact the types of organics, both contaminants and intrinsics, detected [9]. Studies utilizing varying derivatizing agents are required in order to get the full scope of compounds within a specimen.
e) Inter-specimen heterogeneity plays a large role in what organics are detected. This aspect is amplified in breccias, such as Aguas Zarcas and Tarda.
f) Organic contaminants that are found in meteorite soluble organic compound analyses typically be-

long to one of four categories, independent of geography: agricultural products, fuels, pharmaceuticals, and polymers. For example, the Aguas Zarcas meteorite fell on agricultural land in Costa Rica, whereas the Tarda meteorite fell in the desert in Morocco; however both have extensive terrestrial contamination within all four categories (Figure 1).

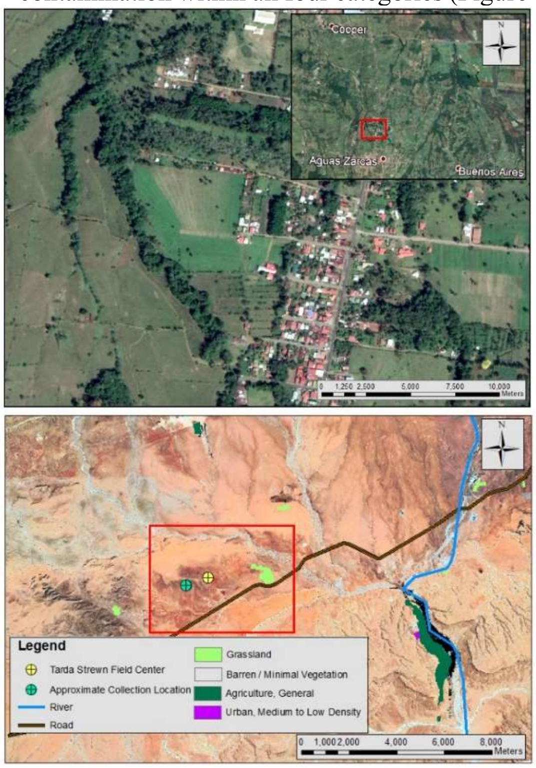

Figure 1. Strewn field maps of the Aguas Zarcas (top, from [5]) and Tarda (bottom, from [6]) meteorite falls.

Conclusions and Next Steps: The rapid contamination of meteorites emphasizes the need for a standardized procedure to document and mitigate contamination of meteorites – especially fresh falls – to preserve meteorites in their most pristine states for future research. Best handling and curation practices determined from the study of meteorites becomes particularly important in preparation for sample analysis from missions such as OSIRIS-Rex, Hayabusa2, and Mars Sample Return. We derived six key recommendations for recovering, handling, and curating freshly fallen meteorites:

1. Meteorite specimens, should be collected as rapidly as possible to avoid the potential or further damage (e.g., weathering) and accumulation of contaminants (either chemical or biological).
2. Extensive site notes should be kept to document strewn field characteristics (land type, weather, season, topography, etc.) and meteorite characteristics (fusion crust, interior exposure, etc.). This includes photos of the meteorite and immediate area prior to collection.
3. Terrestrial samples from the strewn field area should be taken (including water, soil, sand, etc.) to enable later characterization of the contaminants present in the surrounding environment and help inform sources of contaminants on the meteorite. For example, the collection of sand from the Tarda fall area was key to discriminating terrestrial contamination [6].
4. Using gloves and appropriate materials, samples should be collected while photographing, weighing, and documenting any notable characteristics of the sample or its surroundings.
5. Baseline contamination that can be shed from materials and surfaces used when collecting, handling, and storing samples should be documented. Although it is not possible to eliminate contamination entirely, it is possible to mitigate contamination by understanding the sources of possible contaminants from materials and surfaces.
6. How the specimen is handled after collection, including the material(s) and temperature in which it is stored, any analyses or handling conducted, or any activities that have the potential to introduce contamination should be documented. Although storage in colder conditions is recommended, it is just as important to understand how materials interact with the sample at the temperature of storage.

Future work investigating microbial contamination impacts on meteorites is in progress to understand both terrestrial chemical and biological contamination on meteorites and the interactions between them.

Acknowledgments: Funding was provided by Canadian Space Agency FAST Grant 18FAALBB20 and NSERC Grant RGPIN-2018-04902 to CDKH. Frank Florian, Bruce McCurdy, Murray Paulson, Joanne Osborne-Paulson, Connor Paulson, Gary Stonley, Mike Noble, and Juan Poblador are thanked for providing the specimens used in these studies.

References: [1] Sephton M. A. (2004) *Astron. Geophys.,* 45, 2.8-2.14. [2] Elsila J. E. et al. (2016) *ACS Cent. Sci.,* 2, 370–379. [3] McCubbin F. M. et al. (2019) *Space Sci. Rev.,* 215. [4] Tunney L. D. et al. (2020) *Meteoritics & Planet. Sci.,* 55, 1899–1923. [5] Tunney L. D. et al. (2022) *Meteoritics & Planet. Sci.* Forthcoming. [6] Tunney L. D. et al. (2022) *Meteoritics & Planet. Sci.* Forthcoming. [7] Simkus D. N. et al. (2019) *Meteoritics & Planet. Sci.,* 54, 1283–1302. [8] Lee M. R. et al. (2021) *Meteoritics & Planet. Sci.,* 56, 34–48. [9] Orata F. (2012) In *Advanced Gas Chromatography – process in agricultural, biomedical and industrial applications*, edited by Mohd M. A., 83–108.