PLANETARY MATERIALS LABORATORY CAPABILITIES AND FACILITY EXPERIENCE AT THE CARNEGIE INSTITUTION OF WASHINGTON. E. H. Hauri1, C. M. O’D. Alexander1, R. W. Carlson1, G. Cody2, Y. Fei1, L. R. Nittler1, A. Shahar2, S. B. Shirey1, A. Steele2 1Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Rd NW, Washington DC 20015 USA (ehauri@ciw.edu); 2Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd NW, Washington DC 20015 USA

Introduction: The sample characterization and analytical facilities at the Carnegie Institution of Washington (DTM and Geophysical Lab departments) provide an exceptionally wide range of capabilities routinely applied to cosmochemical and planetary science questions, combining technical expertise with scientific vision from project concept through publication, experience in characterization of community standard materials, and operation as a NSF-supported multi-user open facility. Lab instrumentation includes two Nu Plasma high-resolution multi-collector inductively coupled plasma mass spectrometers (MC-ICPMS) instruments, a Thermo Triton thermal ionization mass spectrometer (TIMS), Thermo Finnigan Deltaplus XL and Thermo Delta V Plus gas source mass spectrometers, two Cameca ion microprobes (IMS-6F and NanoSIMS 50L), a UV laser-ablation quadrupole ICPMS, a JEOL field-emission electron probe microanalyzer (EPMA), a JEOL field-emission SEM, a focused ion beam/field-emission scanning electron microscope system (Carl Zeiss AURIGA CrossBeam FIB/SEM), confocal scanning Raman spectroscopy, atomic force microscopy, scanning near field optical microscopy, Fourier transform infrared (FTIR) spectroscopy, three gas chromatography mass spectrometry (GC-MS) instruments, an ultra-performance liquid chromatography tandem mass spectrometer, solid-state nuclear magnetic resonance spectrometer, and fully equipped laboratories for sample preparation, micromanipulation, chemical separation, microbiology and molecular biology.

Laboratory Capabilities: The Carnegie Institution of Washington’s Broad Branch Road (BBR) campus is ideally equipped for planetary studies ranging from the smallest particles in space to experimentally simulating the melting and phase segregation process at work during planet formation and differentiation. Utilizing the many high pressure and temperature techniques available from gas mixing furnaces to piston cylinder and multi anvil apparatus to diamond anvil cells, all stages of planetary formation can be probed. The FIB/SEM and recently installed field-emission EPMA system (JEOL JXA-8530F) have been used to advance research in cosmochemistry, generating high-resolution element maps and obtaining quantitative chemical analyses at the sub-micron scale. The FIB technology allows precision milling to expose tiny inclusions and prepare thin specimens at specific sites for TEM, NanoSIMS, Raman spectroscopic, and synchrotron-based measurements. The combination of precision milling and high-resolution imaging also enables the generation of 3D nano-tomographic maps of small samples. These capabilities allow us to investigate planetary processes and the origin of extraterrestrial materials through analyses of synthetic and natural samples including recovered high-pressure samples, primitive meteorites, presolar grains and interstellar organic matter in meteorites, interplanetary dust particles collected in the stratosphere (IDPs), and samples returned by NASA’s Stardust, Genesis and Apollo missions. These capabilities work in concert with mass spectrometry methods capable of ppt-level detection limits for trace elements (including sub-ppm limits for water and carbon) and geochronologic/isotopic analyses that are capable of analytical precision approaching ±5 ppm [e.g. 1,2].

A recent workshop at Carnegie concentrated on identifying critical techniques and technology development necessary for future sample receiving laboratories. While key techniques peculiar to our current facilities where identified, current deficiencies in sample containment, curation and preparation were discussed with an eye toward future sample return missions. As such an internal research effort is being discussed to address these issues for both geochemistry but also to minimize contamination and false positives for life detection and planetary protection concerns.

An Example from 54Cr Cosmochemistry: A key aspect of CIW-BBR planetary materials research is access to analytical techniques that span many orders of magnitude in spatial resolution, sensitivity, and precision in flexible combinations required by individual scientific investigations. This approach relies on cutting-edge sample preparation and characterization, combined with complementary chemical and isotopic capabilities taking advantage of both high isotope ratio precision and high spatial resolution. One example is the path that led to the discovery of the presolar carrier mineral phase of excess 54Cr in meteorites. The first suggestion of Cr isotopic heterogeneity in the solar nebula came from precise measurements of acid leaches of gram-sized samples of whole rock chondrites [e.g. 3,4]; subsequent investigations pursued this problem in two complementary directions. One approach
involved ultra-high precision isotope analysis at the whole-meteorite scale that discovered that the Cr isotopic compositions of different meteorite groups are distinct from each other [4,5]. Another direction of Cr isotope studies focused on increasingly smaller spatial scales, first to isolate the acid residue containing the largest $^{54}$Cr excesses, then scanning isotope measurements by NanoSIMS to locate the submicron carrier mineral phases of the $^{54}$Cr excess, after which a variety of SEM and TEM analyses were performed to fully characterize the phases [e.g. 6,7]. The first approach required access to ultra-clean lab facilities, mass spectrometers, and analytical techniques capable of ultra-high isotope ratio precision. The latter required access to a variety of instruments to chemically, mineralogically, and isotopically characterize grains at the sub-micron scale. All of these analytical capabilities are present at the Carnegie BBR campus.

**Laboratory Training of Students & Postdocs:**
The intellectual atmosphere for interpreting new results and making discoveries is enhanced at the Carnegie BBR campus due to a very diverse set of background and expertise among the staff and postdocs. A unique aspect of the facility is the direct involvement of senior scientific staff with students and postdocs in instrument design and maintenance, in developing analytical protocols and procedures in the lab, in problem solving, and in communicating results. Senior scientists are active members of their respective research teams in a manner that goes beyond traditional mentoring. This leads not only to improved scientific outcomes but also scientific role-modeling for visiting postdocs and graduate students. Hands-on operation and direct involvement in establishing analytical protocols is a critical component of planetary material analysis that provides the invaluable experience needed to understand what techniques can provide the most useful results, and ensures that both the strength and weaknesses of any given technique, and the data it provides, are appreciated by the user. A key aspect of any future NASA facility will be the ability to train the next generation of scientists in a comprehensive way. The long-term presence of a known, stable postdoctoral/student visitor program at Carnegie combined with the intellectual atmosphere and the direct involvement of senior scientists give the BBR campus a unique capability in research training. Such training is an essential feature of the core capability needed to analyze any NASA samples upon their return.

**Lessons Learned on Facility Operations:**
Importantly, experience at CIW has demonstrated that the approach to operating a successful multi-user facility requires support and dedication on the part of home institution faculty who are personally invested in the operation of laboratory facilities for their own research programs, assuring that development of new methods and standardization proceed in parallel with research measurements. This experience was made clear during operation of the Carnegie SIMS lab as a formal NSF-supported multi-user facility in earth sciences from 1998-2003 (and a de-facto facility for 2 years prior). As a rule, we found that the instrumentation and analytical needs of invested research faculty parallel those that are in demand by the broader community, yet lab facilities such as CIW-BBR generally do not achieve at a high level when run by committee. Experience at CIW has shown that project selection guided by faculty produces higher impact science results than sub-critical acceptance of any project with merely feasible analytical needs, as demonstrated by publication quality and associated citation indexes. Our experience in this arena demonstrated a clear lesson; NASA support in cutting-edge laboratory capacity will be best enhanced and multiplied by careful attention to institutional commitments to laboratories and associated technical staff by the faculty of the hosting institution, and by entraining the expertise of institutional faculty in matching projects of scientific importance with the technical strengths of the facility.

**References:**