Analog Mars Sample Return Workflow

Section 1: Sample Acquisition & Curation

Astrobiogeochemistry Laboratory

Jet Propulsion Laboratory, California Institute of Technology

Kenneth Williford, Michael Tuite

Contents

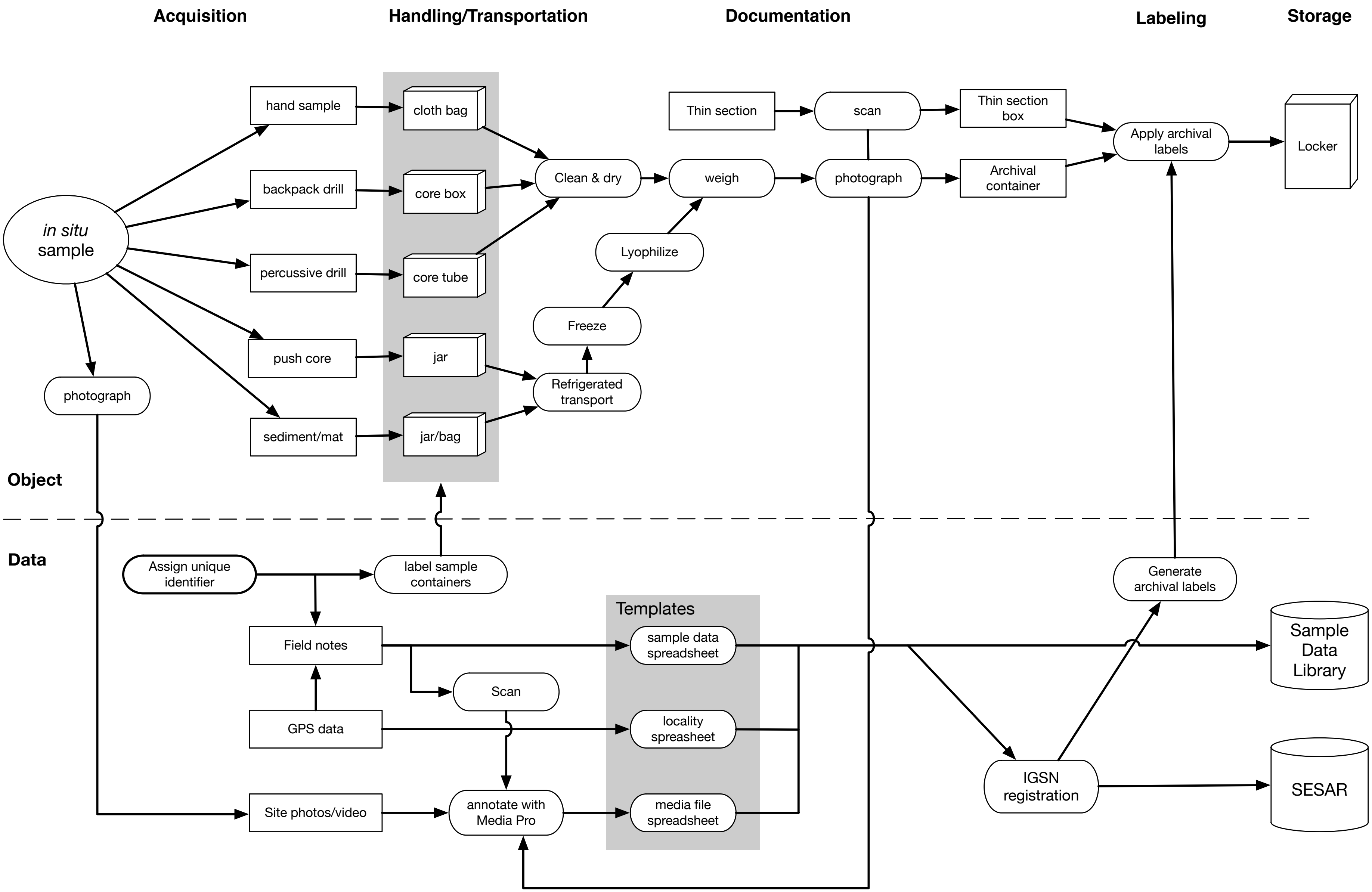
Overview

The scope of this component of the abcLab Analog Mars Sample Return Workflow encompasses the acquisition of samples and related data in the field through the emplacement of both in stable and secure repositories. Acquisition and curation are inextricably tied because good, long-term stewardship of invaluable geosamples, whether from Earth or Mars, begins in the field with the collection of contextual data along with the sample

The objective of this document is to maximize the data yielded by Mars-analog samples that are collected and analyzed by the abcLab in preparation for the potential return to Earth of actual Mars samples. The content of the document is a collection of best practices gleaned from our peers in the astro/ geobiology community at JPL, NASA, and in academia. The effort is undergirded by the premise that analog returned samples should be treated with a deliberate and considered workflow that is as similar as possible to that which actual returned samples will undergo because analog data yields information that is essential to interpreting astrobiological context, anticipating rock properties, and choosing targets for collection by a rover on Mars that are most likely to yield scientific discovery.

Figure: Acquisition/Curation workflow overview

The acquisition/curation workflow is divided into two parallel paths - one for the physical sample itself and the other for the data associated with the sample - and includes five broad steps: Acquisition, Handling/Transporation. Documentation, Labeling, and Storage. In situ samples may be collected via five methods, each with different handling/transportation requirements. The data pathway begins with the assignment of unique field identifiers for each sample which are applied to appropriate sample containers and noted in the field notes along with locality information. Following transportation to the abcLab, samples are cleaned and dried (if necessary), weighed, and photographed. All sample data, locality data, and media annotations are recorded in spreadsheet templates. Data are exported from the templates for web-accessible secure storage in the Sample Data Library and to SESAR to register each sample with an International GeoSample Number. Archival labels are generated using the online IGSN system and are affixed to appropriate archival containers which are then placed into secure storage lockers. Thin sections are scaneed on a flatbed scanner and the images are annotated just as the sample images are. Archival thin section boxes are labeled and stored as samples are.



Acquisition
Handling/Transportation
Documentation
Labeling
Storage
in situ sample
hand sample
backpack drill
percussive drill
push core
sediment/mat
photograph
cloth bag
core box
core tube
jar
jar/bag
Clean & dry
Refrigerated transport
Freeze
Lyophilize
weigh
Thin section
scan
photograph
Thin section box
Archival container
Apply archival labels
Locker
Object
Data
Assign unique identifier
label sample containers
Field notes
GPS data
Site photos/video
Scan
annotate with Media Pro
Templates
sample data spreadsheet
locality spreasheet
media file spreadsheet
Generate archival labels
IGSN registration
Sample Data Library
SESAR

Acquiring Samples

Sent samples

When working with collaborators, samples are often shipped to the abcLab. Communicate clearly with the sender your expectations regarding sample quality and security. Ensure that the samples are carefully packaged and marked as scientific samples to avoid close inspection and delays in delivery. Vials of white powdered rocks may be problematic.

An example of shipped samples. These powdered samples in scintillation vials were wrapped in bubble wrap in box lined with more bubble wrap. They arrived safely.

Field work Preparation

Every field excursion to acquire samples must have a designated Lead investigator who will complete the required administrative requirements and lead the field team in addition to a Safety Lead. The Safety Lead must ensure that all participants have completed Heat Stress Safety Training. This is available online through JPL's Learning Management System. There should be at least two members of the field party who have completed a certification course in CPR and First Aid. A course is available through the JPL Fire Department. If there will be any flammble liquids, flames, or other fire hazards, at least one person must complete the Fire Safety and Fire Extinguisher Training course also offered by the Fire Department. A JPL-approved First Aid kit must accompany the field team. These are available througt iProcurement.

Acquire any necessary permits or permissions well in advance. Determine who the land owner is and contact the individual, corporation, state or federal agency. Generally, research and collecting on land managed by the Bureau of Land Management does not require a permit. However, you can obtain a letter of support from the appropriate regional BLM office if pressed to prove that you may collect.

Use Google Maps to create a map with scale of the proposed study area. The Safety Office would prefer turn-by-turn directions for every location but this is seldom possible.

Safety & Environmental Requirements

Every trip to the field to collect samples entails JPL-specific safety and environmental requirements. Planning as far in advance as possible will alleviate some potential headaches. Start by submitting a Travel Reservation Form to the section office. This will allow you to recieve reimbursement for expenses.

JPL's Office of Occupational Health and Safety requires the submission of Form 7015 Off-lab Field Research Safety Plan for any field work. Provide a minimal description of the work to be undertaken. Also provide a map of the study area and as much specific information about the location as possible. The list of potenial hazards should include, but is not limited to:

- Climbing/slipping/falling
- Getting lost
- WIldlife
- Rattlesnake bites
- Dehydration
- Heat sickness/heat stroke
- Fire
- Flash floods
- High tides - use a tide table
- Automobile accident
- Medical emergencies - know the location of the nearest hospital

The Heat Illness Plan is an addendum to Form 7015 that is to be completed when temperatures are expected to exceed 80°F. The form is primarily a regurgitation of the content of the required Heat Illness Traiining. Have every participant sign the form to indicate that he/she has completed the training. If there will be flammable liquids at the field site, such as gasoline, you will need to borrow a certified fire extinguisher from the JPL Fire Department.

Form 7406 Request for Environmental Impact Analysis must be submitted to the Office of Environmental Affairs at JPL. Endeavor to submit the form at least one week before the activity. If the activity includes drilling with the backpack drill, the gasoline-powered motor will produce emissions. You will need to reassure the

Checklist

☑ Form 7406 Request for Environmental Impact Analysis

☑ Form 7015 Off-Lab Field Research Safety Plan

☑ Addendum: Off-Lab Heat Illness Safety Plan

☑ Travel Reservation Form

☑ Approved First Aid kit

☑ Required training

☑ Permission/permit

☑ Fire extinguisher

Contacts:

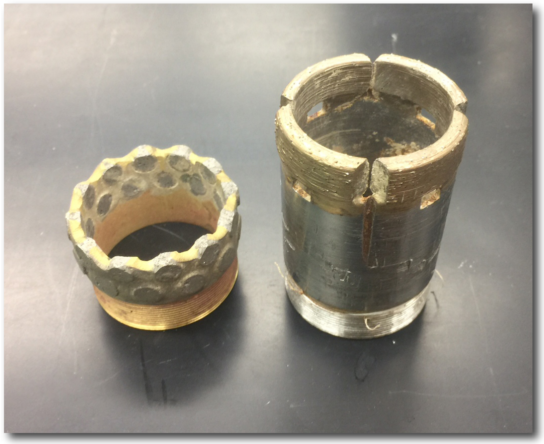
Travel: Maria Alcazar	818 888-8888
Safety: Charlene Paloma	818 888-8888
Environmental: Faustino (Tino) Chirino	818 888-8888
JPL Fire Department	818 888-8888

Acquiring Samples

The Shaw Backpack Drill

Core samples are preferable to outcrop samples for geochemical analysis because they have not been exposed at the surface to chemical and physical weathering. The Shaw Backpack Drill is a gasoline-powered coring drill. The abcLab uses the 41mm ID version and owns 20m of core tubing. The drill bit is lubricated by a constant supply of low-pressure water from a hand-pumped canister. Two canisters fit into the backpack. A much larger 25 gallon plastic tank can be carried in the back of a truck or car to refill the canisters in the field. A tripod equipped with block and tackle facilitates the extraction of the heavy drill string from the borehole. While the drill is hypothetically "backpack" portable, with water, steel tubes, fuel, and tools it requires a small team to deploy. Required safety gear includes closed-toe shows, safety goggles, hearing protection, long sleeves and pants, and a fire extinguisher.

The drill seems best suited to relatively hard, competent rock. Our experience drilling in relatively soft, clay-rich sediments met with mixed success (see Case Study on page 18).



Examples of two drill bit options for the Shaw drill. The Elephant Tooth diamond bit on the left will readily cut rock of any hardness. The diamond impregnated bit on the right, however, allows more water to pass through the bit, improving lubrication at the cutting edge.

The Shaw Backpack Drill 41mm package consists of the gasoline-powered engine, pressurized water canisters, gasoline bottles, core tube segments, drill bits, the core pusher for extracting the core from the tube, the backpack itself nnd some small tools and accessories. The abcLab has 20 meters of core tube segments as well as a large tripod which can be used to haul up long drill strings.

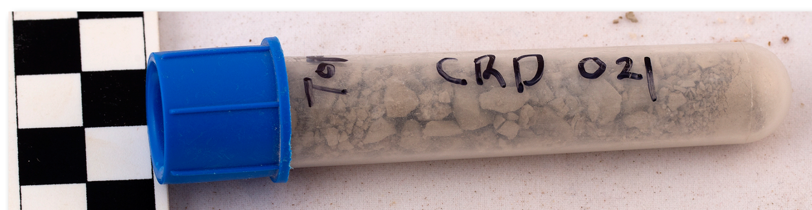
Bosch Rotary Percussive Drill

The drill that will be deployed on the Mars 2020 rover for the purpose of collecting the samples that may one day be returned to Earth employs a rotary percussive action to acquire a sample core. The Boschhammer percussive drill works in an analogous fashion and, therefore, serves as a way to collect samples that are mechanically similar to what may be returned from Mars.

Users report difficulty in obtaining purchase on the surface of the rock that is to be drilled. Most especially on very hard rocks, the drill bit bounces around the surface of the rock even when significant force is applied to keep it in place. Once drilling commences, a large fraction of the target rock is reduced to powder which accumulates at the borehole. The drill bit becomes very hot during operation and cools slowly. When complete, the core is in the form of small fragments packed in the bit. The small pieces are removed with tweezers and stacked in a tube, preserviting their stratigraphic order. The drill fines are collected in an ashed glass jar. The cored rock itself might also be collected so that it might later be sawn and studied in detail alongside the core.

The Boschhammer percussive drill is similar in its mode of operation to the drill that is being developed for the Mars 2020 rover mission to Mars that will drill and cache samples for possible subsequent return to Earth.

In addition to collecting the fragmented core pieces, we collect both the drilling fines and, when possible, the drilled rock.



An example drill core from produced by the percussive drill. Note that the "Top" of the core is marked below the blue cap.

Data Collection in the Field

Data collected while in the field provide important contextual information that is often critical for later interpretation of analytical results. Avoid the temptation to "write it down later." You will forget details that you see at the outcrop. The data fields listed below are based upon disciplinary standards and will map readily into the IGSN sample registry and the Sample Data Library. The System for Earth Sample Registration (SESAR) and the USGS offer controlled vocabularies for some data fields (see Links on page 19).

Sample data

fieldID - a unique identifer (could be from a precompiled list of sampleIDs).

parentID - where appropriate, the unique identifier of the samples parent.

localityID - a unique identifier for the locality

material - rock, sediment, biology, soil, mineral, ice, gas

classification - Sedimentary>Siliciclastic or Carbonate

sampleType - usually an "individual sample"

fieldName - an informal classification (e.g. mudstone, clam, gypsum)

description - describe features such as components, texture, color, shape, etc

geological age - use hierarchy eon > era > period > epoch > age

geological unit - use hierarchy group > formation > member > unit

otherGeoName - any other relevant geological name (e.g. Perma sill)

collectionDate - in the format yyyy-mm-dd

datePrecision - usuallly "day"

collector - name of the person who collected the sample

sectionHeight - the height of the sample in a measured section

coreIntTop - the top of the core section containing the sample

coreIntBottom - the bottom of the core section containing the sample

depth - the depth of the sample in a core

measurementUnit - the measurement units (meters, centimeters, feet, etc.)

Locality Data

localityID - a unique identifier for the locality

localityName - the locality name (add otherName if appropriate)

description - a brief description of the locality

latitude & Logitude - in decimal degrees

latEnd - if the locality is an extended section, the latitude of the end point

lonEnd - if the locality is an extended section, the longitude of the end point

elevation and elevationEnd - begining and ending elevation in meters

navType - usually GPS

datum - usually WGS84

date - data that the locality data were collected

physioFeature - the name of the regionally dominant physiographic feature

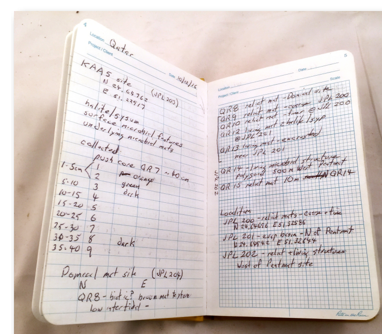
country > state > county > city

accessNotes - note hazards, challenges to access, including land owner contact

embargo - should the locality data be embargoed for a period of time?

> Make a list of sample and locality IDs before you go into the field. Print out the lists and keep them with your notebook. If you are able to use a laptop in the field, use the abcLab Field Data templates to collect data. Make sure container labels match notebook entries.

The field notebook is the first and authoritative record of a sample's entry into the curation workflow. Ensure that sample identifiers recorded in the notebook are consistent with those placed on sample containers. Abundant contextual information will make it easier to write sample descriptions and image captions later. Record longitude and latitude in decimal degrees not just as waypoint names or numbers.



Handling and Transporting Samples

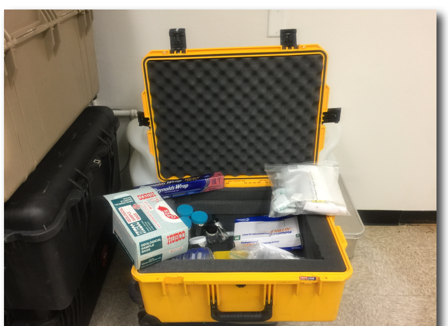
Careful attention to sample handling and transportation will minimize samples' exposure to environmental contamination, physical damage, and administrative obstacles.

In the field and in the lab, handle samples as little as possible. Place newly collected samples in clean contaners using gloved hands. For outcrop samples, cotton duck or muslin sample bags will not trap water and are chemically inert.

When it is possible to do so, carry the samples you have collected in your vehicle or luggage. If it is necessary to have the samples shipped to JPL, select a container that will withstand the rigors of rough handling - wooden crates or plastic buckets with lids work well. Ensure that samples are dry before they are sealed in containers in order to prevent the growth of fungi.

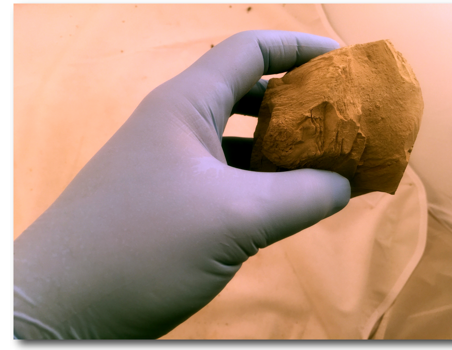
While being transported, samples requiring refrigeration, such as microbial mats, should be kept in an insulated box and returned to the lab as quickly as possible.

When collecting samples outside the U.S., adhere to all local laws regarding the export of scientific samples. Work with your local collaborators to procure a letter from an academic institution or government agency that explains that samples were collected legally and are being transported in accordance with the law.



This Pelican case provides a convenient and portable collection kit that includes gloves, foil, sample bags, ashed jars, teflon tubes,KimWipes, camera and accessories, notebook, scupulas and other small tools. The case provides sufficient space to transport at least the most fragile or valuable samples back from the field location

In the field and in the lab, samples should never be handled with bare hands so as to avoid organic contamination. Blue nitrile gloves provide a safe barrier against contamination.



An example of a letter authorizing the transportation of scientific samples out of the host country, Qata in this case. Carry a copy of letter on your person while traveling and also place a copy with the samples.

مركز التنمية المستدامة
Centre for Sustainable Development

كلية الآداب والعلوم
College of Arts and Sciences
QATAR UNIVERSITY جامعة قطر

2016/10/16

السيد/ رئيس إدارة الجمارك المحترم

مطار حمد الدولي

تحية طيبة وبعد،،

يهديكم مركز التنمية المستدامة أطيب تحياته ويحيطكم علماً بأن الدكتور مايكل توت سيغادر الدوحة ومعه بعض العينات البيولوجية التي ستستخدم لأغراض بحثية بحتة لصالح جامعة قطر. الرجاء تسهيل مرور هذه العينات.

هذا وتفضلوا بقبول فائق الاحترام والتقدير ،،

حمد آل سعد الكواري

مدير مركز التنمية المستدامة

Center for Sustainable Development 16 OCT 2016 مركز التنمية المستدامة

تليفون : ٤٤٠٣ ٦٨٣١ (٩٧٤+) فاكس : ٤٤٠٣ ٤٩٣١ (٩٧٤+) ص . ب : ٢٧١٣ - الدوحة - قطر
Tel.: (+974) 4403 6831 Fax: (+974) 4403 4931 P.O.Box: 2713, Doha - Qatar
E-mail : sdchair@qu.edu.qa * Website:www.qu.edu.qa

Documentation

Sample photography

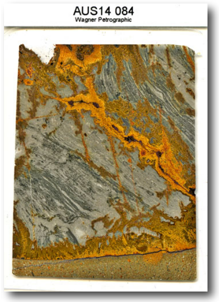
If a picture is worth a thousand words, then carefully constructed sample images contain an abundance of information. Where possible, every sample should be photographed in its field context and then again as a discrete object in the lab.

For lab photography, every image must include a scale, color calibration target, and the unique sample ID. Samples are placed in the light tent which helps to create an evenly lit object. The tungsten Tota lights emit a light temperature of 5200K, so turn off the overhead fluorescent lights when shooting in order to avoid mixed lighting sources. Generally, each sample will be represented by a single photograph so it is important to place the sample in such a way that its most important features are visible. For larger or more heterogeneous samples, multiple photographs may be necessary.

The abcLab camera is a Canon 6D which is a full-frame digital SLR. Images may be captured in RAW format but should be converted to TIF before being added to the media archive. The preferred lens for sample images is the Canon 105 mm Macro (f/2.8). The lens works well for small samples and at longer distances allows for sufficient depth of field to keep larger samples completely in focus.

Every petrographic thin section is to be scanned at the maximum optical resolution (1200 dpi) provided by the Epson Perfection flatbed scanner in the sample handling and storage room (building 183, room 200). Thin section image filenames should include the prefix “TS_” and be saved as TIF files in the media archive directory. When annotating thin section images in MediaPro, indicate the sampleID for the parent sample so that thin section images are linked to a sample.

The sample photography setup consists of two tungsten Tota lights, the light tent, and Canon D6 with a remote cable release on a Bogen tripod. The lens used is usually a Canon 105mm Macro. The fluorscent lights in the room are turned off while shooting to avoid mixing light temperatures.



A petrographic thin section scanned using the Epson Perfection VX750. At a 1200 dpi resolution, the scanner provides enough detail to identify major features in the sample and help to identify targets for microscopic analysis.

A properly photographed sample should include a scale, color calibration target and the sample ID. This large sample required a high f-stop (f/22) and long exposure in order to achieve sufficient depth of field to keep the whole sample in focus.

The Media Catalog

All media associated with samples, including images, video, and PDFs, are stored in the "media" directory on the JPL-hosted server account:

smb://b600-cdot3-svm1/abclab.

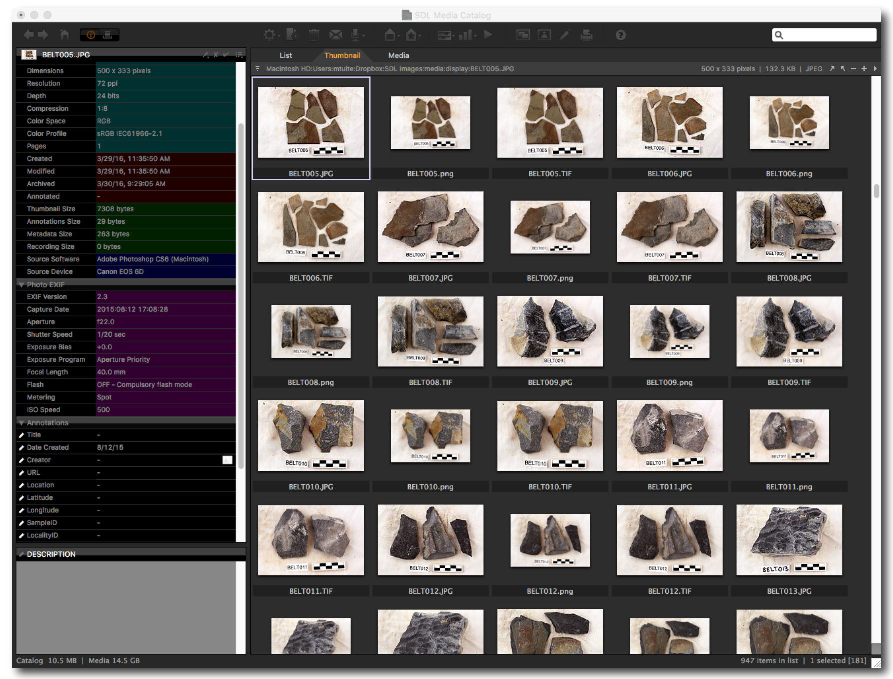
Within the media directory are three subdirectories: Archive, Display, and Thumbnails. Archive images include uncompressed and compressed formats such as TIF, RAW, and JPEG. Images added to the Archive directory are automatically duplicated to the Display directory as minimally compressed JPEG files and to the Thumbnail directory as resized PNG files. Other media file types (e..g. PDF, MOV, MPG) should be placed directly into the Display directory. The contents of the Display and Thumbnails directories are automatically mirrored to the abcLab Sample Data Library web site.

Media file annotation is done within the SDL Media Catalog, a MediaPro (Phase One) file in the root directory. The List view in MediaPro allows direct entry of text in annotation fields. The minimum annotation for any media file includes these fields:

File Name (automatically filled in)
Creator - name of the person who created the media
Description - a brief description or some keywords
Capture Date (automatically filled in)
At least one of: **SampleID, LocalityID, ActivityID, AnalysisID**
File Type (automatically filled in)

Other metadata, including latitude and longitude if available, are added automatically to the record for that file.

Media annotation data need to eventually make their way into the web-based Sample Data Library. There is not as yet a direct path for media annotation data from the Catalog to the SDL. Select the files for which you would like to export the data, select Export, and choose the SDL Template to export as a CSV file. The resulting file can then be imported directly into the Media Data Spreadsheet Template (Appendix 2).



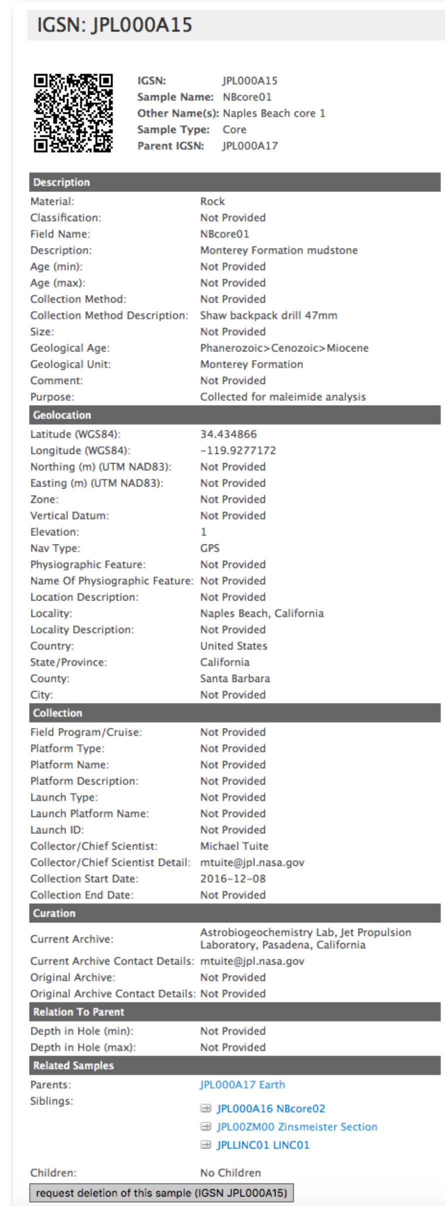
The MediaPro interface allows the user to view the image collection as a text list, thumbnails, or individual media files.

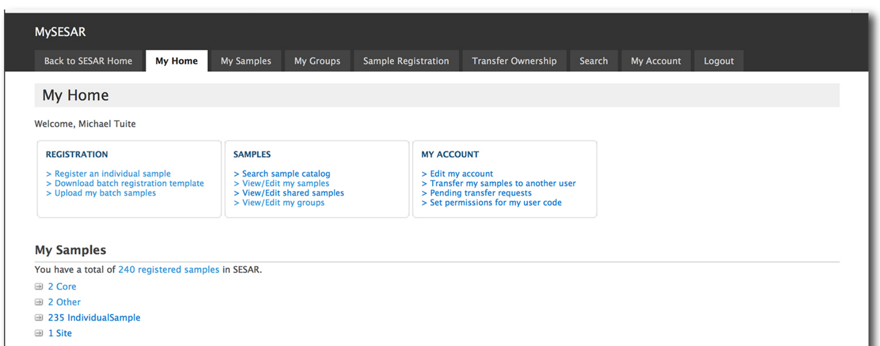
The International GeoSample Number (IGSN)

The IGSN or International GeoSample Number is an alphanumeric code that is assigned to samples and related sampling features such as drill holes or sites in order to ensure their unique identification and unambiguous referencing of data generated by the study of samples. The IGSN is a persistent identifier for a sample just like a DOI is for a publication. Essentially, it makes geosamples into referencable objects on the "Internet of Things." The IGSN should be included in all publications that refer to the sample. The IGSN need not be used as the primary local identifier for the sample. A unique identifier should be assigned at the time of collection while the IGSN will typically be assigned after the sample has been collected and returned to the lab.

The IGSN system is administered by SESAR, the System for Earth Sample Registraion and supported by the National Science Foundation. Samples can be registered individually or in batches. Either method requires a user account and a three-letter prefix that is assigned to each nine-character IGSN. The abcLab has registered the prefix "JPL." To register a single sample or a batch, go to http://www.geosamples.org and log in. Registering a single sample requires that you fill out a web form containing the fields in the sample IGSN record to the right. Most of the fields are not relevant. To register a batch of samples, you select the fields that you want to have added to a spreadsheet template. When the template is downloaded, you can copy and paste columns from the sample data spreadsheet template (Appendix 2) you used to record sample data. Create unique IGSN numbers in the form JPLxxxxxx. There is no reason you cannont incorporate your orignial local identifier into the IGSN; for instance "JPL00ZM01" for the sample ZM01 so long as each is unique. You will be advised of any errors during the upload process.

An IGSN record for a core collected by the abcLab in the Monterey Formation at Naples Beach. The record includes basic descriptive, location, collection, and archive information. There are links to images and other media, parent and sibling objects, and a link to the sample's record in the Sample Data Library. The QR code provides a link to the IGSN record.





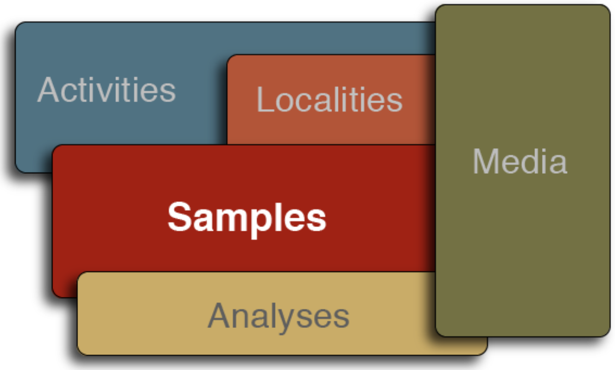
The SESAR interface allows a registered user to register individual samples, gererate custom batch registration templates and then upload them. The user may also search, view, and manage her samples as well as manage the account. The Groups feature allows the user to group samples by project, core, site, or other category.

The Sample Data Library

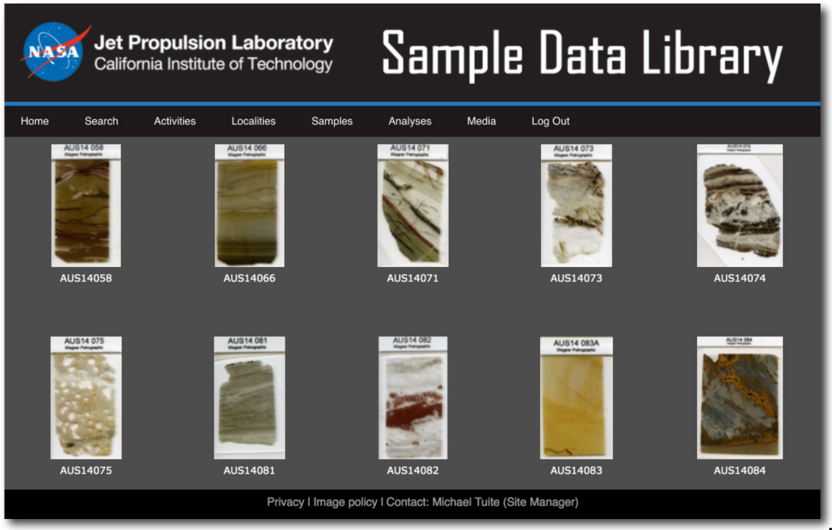
The Sample Data Library (SDL) is the repository for data generated by the abcLab. The SDL is a sample-based data management system that is built with Amazon Web Services tools including web accessible file storage, a MySQL data base, and a virtual Unix server running Apache and PHP. SDL metadata are based on domain-specific standards. Data for each sample include geographic location and geological age, images, analytical results and raw instrument data, collection information, and the depth of a sample relative to others if collected from a core. Samples are assigned unique identifiers and are registered with the International Geosample Number (IGSN) registry so they are discoverable via the web.

Metadata are adapted primarily from two sources: The USGS Geological Collections Management System (GCMS) and the System for Earth Sample Registration (SESAR). The primary tables in the MySQL database that underlies the SDL are: Samples, Activities, Localities, Analyses, and Media. Each entry in each table includes a unique identifier: sampleID, activityID, localityID, analysisID, and mediaID. Links among these identifiers serve to link every sample to the activity to which it has been assigned, the locality from which it was collected, the analyses to which it has been subjected, and the media associated with it.

Data may be edited or added to SDL tables using a tool such as Sequel Pro. New records can be added manually or imported as batches to the Samples, Localities, and Media tables from the Sample Data Spreadsheet Template (Appendix 2).



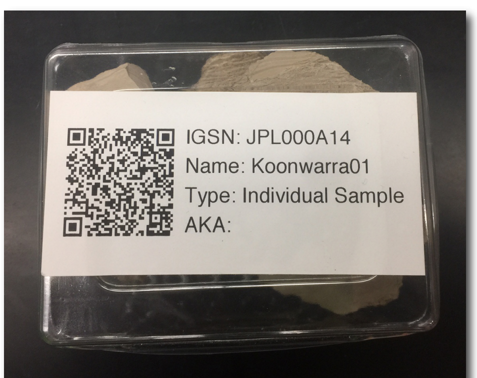
The abcLab Sample Data Library is a sample-based data collection that integrates multiple laboratory analyses of samples. Samples are associated with localities. Both samples and localities are associated with activities which may represent projects or events such as field trips or research programs. Raw and processed data are available for each type of laboratory analysis to which a sample is subjected. Media of any type or format are associated with samples, activities, localities, and analyses.



Labeling

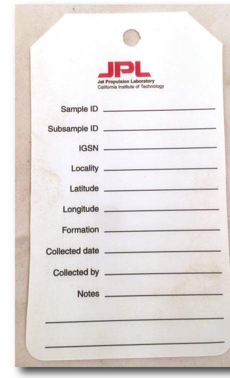
The purpose of labeling a sample is to ensure that it remains findable well into the future. The label should include the minimum information that is necessary to identifiy the sample. The label should be firmly affixed to the sample or the container in which it has been placed. It should also be made of a material that will remain stable and readable for an extended period of time (at least decades).

In order to create a uniform archival label consisitent with other sample repositories, the abcLab uses labels formatted by the IGSN registration system. The SESAR user interface permits users to select a list of samples for which labels are to be generated and then produces a downloadable PDF. By default, the IGSN-generated archival label includes four fields: the IGSN, the name or local identifier, the sample type, and an Also Known As (AKA) field. The label also includes a QR code containing a URL that resolves to the IGSN record for that sample.

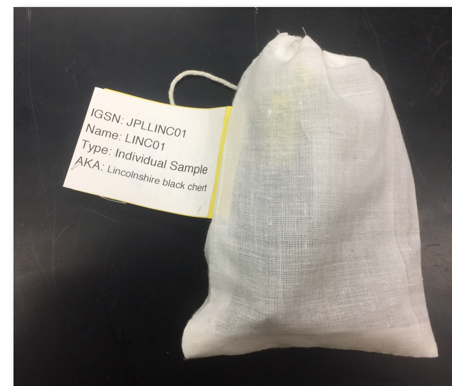


An example IGSN-generated archival label for a sample in the abcLab repository.

A Tyvek label can be firmly affixed to large samples using wire. These labels can be used as temporary labels attached in the fiield with information filled out in the provided fields using a permanent marker. They may also serve as archival labels with an IGSN-generated label affixed to the opposite side. The labels can also be affixed to cloth sample bags that do not have a label.



In the field, a sample identifier and other information can be written on the yellow tag incorporated into Hubco cloth sample bags. Later, a IGSN-generated archival label can be attached to the yellow label.



The Brother QL-1050 prints 4" labels of any length at 300 dpi. The abcLab has adopted this printer as the prefered model for generating archival labels.

Containers

Sample containers must provide stable and secure storage for and extended period of time (at least decades). Sample containers should keep samples clean and dry. They should be chemically inert. They should also be labeled for identification so that samples can be found.

Individual sample containers may include cloth sample bags, jars, and plastic bags. Cloth sample bags should be made of cotton muslin fabric and samples stored in these bags should not be susceptible to oxidative degradation. Delicate samples or those that may eventually be subjected to organic geochemical analysis may be wrapped in ashed aluminum foil and then placed in cloth bags. Powdered samples should be stored in ashed glass jars with a lid lined with ashed foil. Small plastic Ziploc or Whirlpak bags may be appropriate for some samples, such as thin section billets, but should be avoided. Large samples that don't fit into a large bag and can't be cut into smaller pieces may be placed in a fiberglass bin lined with one or more muslin bags.

Sample groups, such as a stragraphic section or samples from a site or field trip, should be stored together in a bin. Bins, core boxes, thin section boxes, and individual samples are placed in clean, dry lockers. Because a primary responsibility of good sample curation is knowing where a sample is, this hierarchy of containers is captured in the Sample Data Library by assigning a unique identifier to every container. Ideally, the location of every sample from the building to the room to the locker to the bin or drawer is recorded and remains current as samples are moved.

Ashed glass jars with ashed foil-lined lids provide a stable container for powdered samples.

Storage lockers in Building 183, room 200 at the Jet Propulsion Laboratory provide stable and secure long-term storage for samples. Blue fiberglass bins are able to support several hundred pounts of rock and are used to hold individual samples in bags and jors.

Core boxes are lined with aluminum foil and have an archival label affixed where it is visible. If the core has been cut and sampled the box may only contain a portion of the original core.

Archival thin section boxes for both regular and large format slides provide protection for delicate glass slides.

Case Study: Pilbara core samples

In 2014, Ken Williford and David Flannery traveled to the Pilbara region of Western Australia in order to collect samples of some of the oldest preserved fossil organisms in an environment that may have been analogous to an earlier, wetter Mars. They brought along the Bosch percussive drill with the explicit intention of collecting samples like those that might be collected by the percussive drill that will be part of the Mars 2020 rover's suite of tools. The drill performed well as several cores were recovered.

Although the field campaign resulted in a unique and important collection of samples that will likely contribute to research for years to come, producing metadata to document the abundant samples and images that were returned has been problematic. Collecting samples and images is always fun. Documenting them after returning from the field when other matters are pressing can be tedious and inconvenient. In an effort to regularize sample naming and identification, a list of sample identifiers was made up before departure. A spreadsheet was prepared for input of data electronically while in the field. This step eliminated any ambiguity in labeling and referencing samples in field notes.

The spatial orientation of these core fragments has been preserved by encasing them in foil. The spaces spaces between the fragments was later filled with epoxy to create a solid core. That core could then be cut and polished for subsequent in situ analysis.

The oldest confirmed fossil life on Earth is found in the Pilbara Basin of Western Australia. These rocks may be good analogs for environments that might have supported microbial life on early Mars.

The Bosch percussive drill was used to extract short cores from Archean stromatolites. The power of the percussive drill tends to fragment the core, leaving the core in small pieces within the bit.

The fragmented pieces of core were carefully removed from the bit, preserving their relative spatial relationship.

Case Study: Qatar microbial mats

In March 2016 Dr. Kenneth Williford traveled to Qatar as part of a collaborative project to study the role of microorganisms in the formation of dolomite in sabkha environments. Dr. Michael Tuite made a subsequent trip in October 2016 and collected a variety samples. The hyper-arid, high salinity environment that exists where the desert and ocean meet may be a good analog for early aqueous environments on Mars.

Living microbial mats were easily sampled with plastic tubes pushed through the rubbery surface into the underlying sediments. The tubes were placed in ashed jars or clean teflon tubes, sealed, and placed in a hotel refrigerator to retard metabolic reactions and degradation of the samples. Other mat surfaces were simply scooped up and placed in ashed jars; however, the push cores had the advantage of preserving the spatial structure of the mat.

A push core was collected from an evaporitic basin encrusted with halite and gypsum. The split core was divided into segments based on color changes and those segments were scooped into clean vials. Another core was collected from a site that six months prior had been inundated with seawater and covered with a mat but was now just sand with a hard surface crust. This core was divided into 5cm intervals, each loaded into a clean vial. In each case, the vials were refrigerated until departure.

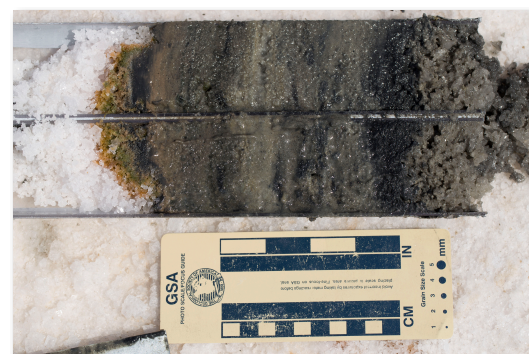
Tuite collected samples of a half-dozen different living mat morphologies as well as several hard surface crusts where mats had previously existed. Tuite also collected two larger mat fragments which he placed in large WhirlPak bags in hope of returning them to the abcLab in viable condition.

On return to the abcLab, all core, crust and mat samples (except the two larger samples) were frozen at -20°C and lyophilized. During the lyophilization process, salts were drawn to the surface of the mat samples changing them from dark gray to white. The samples were registered with SESAR and labeled with archival IGSN labels.

Sample tubes each contain a 5 cm segment of a core collected from moist sand that had been submerged six months earlier.

A push core collected with a thin plastic tube easily punctured the mat surface with complete recovery of ~20cm. The core was placed immediately in a tall ashed jar, kept in a hotel refrigerator until departure, and then frozen and lyophilized upon return to JPL.

Surface crust fragments were collected in large Whirlpak bags. They appeared completely desicated and were frozen upon return to JPL.



A split push core (top to the left) showing live photosynthetic pigments below halite/gypsum surface layer with organic rich layers below.

Case Study: Naples Beach coring samples

In December 2016, Michael Tuite led a group from JPL to Naples Beach in Santa Barbara County, California with the objective of obtaining one or more cores of the Miocene-age Monterey Formation using the Shaw Backpack Drill. The exposure of the Monterey is a well-studied section and features a variety of lithologies including organic-rich mudstones. On an earlier reconnaissance trip, Tuite had collected a hand sample that was analyzed in the abcLab and evaluated for the presence of maleimides, a chlorophyl degradation product. The maleimdes were of sufficient abundance to warrant collecting a relatively short core, no more than 5 meters in length, for a study of maleimide-specific isotope values of carbon, nitrogen, and hydrogen.

Access to the drill site was possible via a ~1 mile hike from a public parking are along a rocky beach. Hauling the drill and water made this a daunting prospect. Vehicle access to the site is available through a locked gate on private property. We were able to contact the property manager and secure access to the site. Because Naples Beach lies within a designated Marine Protected Area, we sought permission from the California State Department of Fish and Wildlife Management. In discussion with that office, we determined that because we would be working above the mean high tide line, a research permit was not required. This was sufficient to satisfy JPL's environmental impact requirements.

The safety plan for this field work included mitigation of risk for the dangers posed by the proximity to the ocean and the fuel used to power the drill. Using tide tables, we determined the best date and time to work at low tide and allow ample time to enter and exit the beach. Tuite completed Fire Safety and Fire Extinguisher training with the JPL Fire Department and a JPL-certified fire extinguisher accompanied the drill.

Drilling the Monterey mudstones proved very challenging. Because of their high clay content, the rocks readily absorbed the water that lubricates the drill string. The drill was frequently stuck and the core segments were very difficult to remove from the core tube. Nevertheless, two separate 2 meter cores were recovered, sufficient for the proposed study. At the drill site, the wet cores were laid out in foil-lined core boxes and transported back to JPL. The cores were allowed to dry for several days before the boxes were sealed. The cores were registered with SESAR and archival IGSN labels were affixed to the core boxes.

The drill site on Naples Beach at low tide. The steeply dipping strata and high clay content made the drilling and core recovery very challenging.

The recovered core fragments totaling about 2 meters were placed in a foil-lined core box and then photographed with scale and color guide.

Case Study: Antarctic K/Pg section samples

In early 2016, Dr. David Flannery traveled to Seymour Island off the Antarctic Peninsula as part of a Caltech-sponsored research expedition. Among the samples he collected were 45 from a stratigraphic interval that spans the mass extinction event at the Cretaceous/Paleogene (K/Pg) boundary. The Zinsmeister section (named for a geologist who had previously studied the site) consists of grey siltstones that are poorly consolidated as well as concretions that often contain fish and other vertebrate fossils. Flannery collected samples at 30cm intervals by digging beneath the weathered surface. The extreme cold made collecting hand samples challenging. The samples were wrapped in ashed foil pouches which were then placed in cloth sample bags.

The volume of the samples collected prohibited Flannery from carrying the samples back to JPL himself. Instead, wooden crates were assembled onboard the research vessel and the samples were transferred to another ship to make their way over a three month period to the Port of Los Angeles. This method of transportation was suboptimal but not negotiable. When unpacked, no signs of mold were noted. The samples were transferred to ashed glass jars and placed in a -20°C freezer. Three jars at a time were placed in the lyophilizer and freeze dried for at least 48 hours. Samples were registered with SESAR and archival IGSN labels were applied to each jar. Jars were placed in a locker drawer in the abcLab sample repository.

Dr. David Flannery points to concretion interval immediately above K/Pg boundary at the Zinsmeister section, Seymour Island, Antarctica.

This concretion contains rib bones and the stomach contents, including gastroliths, of a very Late Cretaceous pleiosaur.

[sub new pic with labels] Forty-five samples collected at 0.3 meter interval span the K/Pg boundary. The poorly consolidated siltstone samples were lyophilized upon reciept and placed in ashed glass jars.

Online Resources

United States Geological Survey, Geological Collections Management System: https://pubs.usgs.gov/circ/1410/

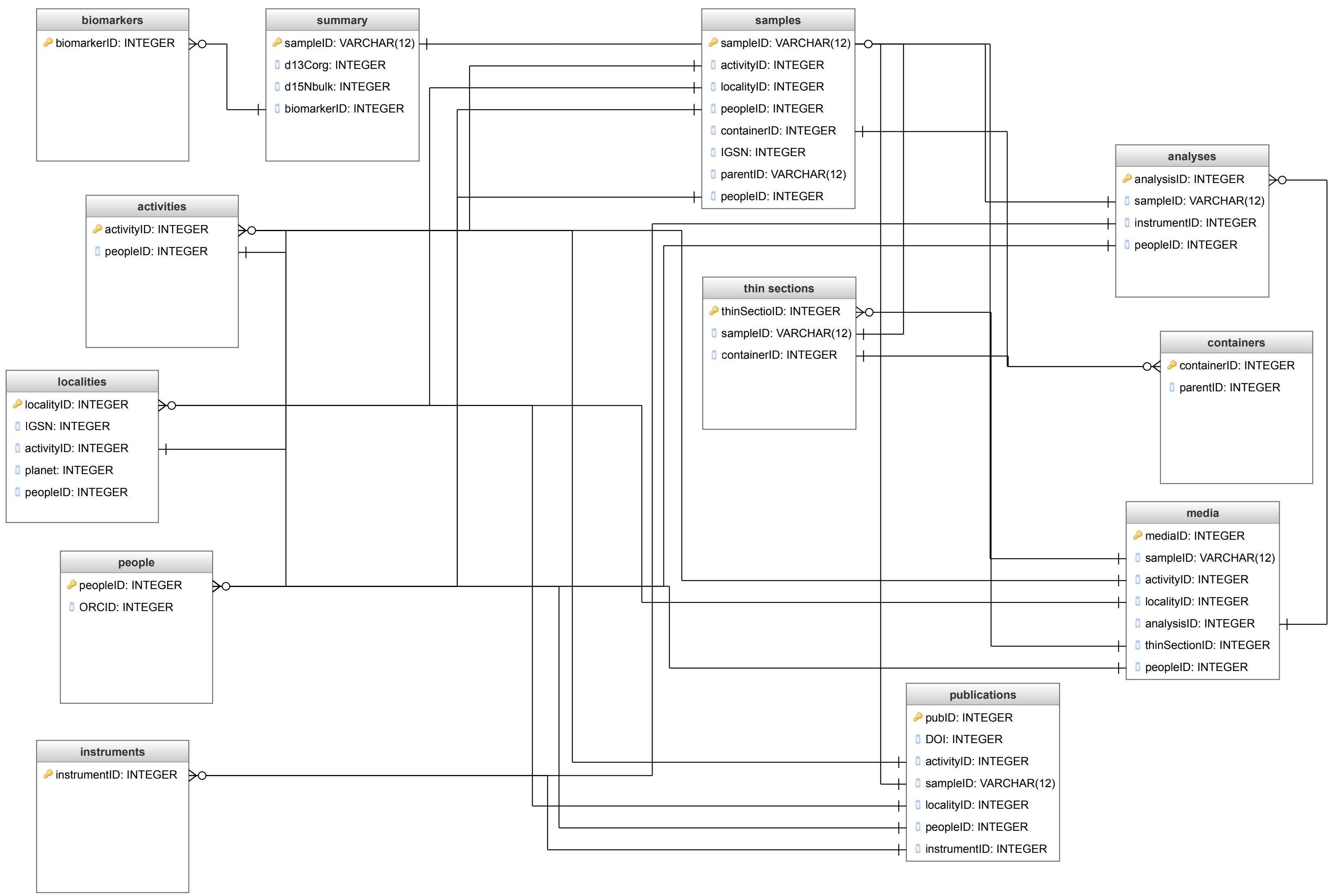
System for Earth Sample Registration (SESAR): http://www.geosamples.org/

Shaw Backpack Drill: http://www.backpackdrill.com/

The Sample Data Library: https://abclab.jpl.nasa.gov/

Appendix I: JPL Forms

Appendix II: SDL Relational Database Structure



Appendix III: Pilbara Core Samples Report