MRD 136, 137, 138 and 139

Summary of Requirements

MRD-136 (2.9.1) Identify and map the distribution and geologic context of all craters on ≥80% of the surface of Bennu ≥5 m in diamete

MRD-137 (2.9.2) Identify and map the distribution and geologic context of all boulders on ≥80% of the surface of Bennu ≥21-cm in longest dimension

MRD-138 (2.9.3) Identify and map the distribution and geologic context of all regions on ≥80% of the surface of Bennu ≥1 m in shortest dimension where regolith is present

MRD-139 (2.9.4) Identify and map the distribution and geologic context of all linear features on ≥80% of the surface of Bennu ≥1 m in width and ≥10 m in lengt

Data Products Required

MRD-136 : Global Crater Geology Map (MRD-136)

A map of the size and physical location of all impact craters on the surface of Bennu and their geological context delineated.

Inputs for time-sensitive "Global Crater Feature Map"

- Global Mosaic @ 21-cm resolution (MRD-121)

- Global Topographic map (MRD-122)

Inputs for long-term science "Global Crater Geology Map"

- Global Color Ratio Maps (MRD-141)

- Global Reflectance Factor Maps (MRD-154)

- Global Bond Albedo Map (MRD-154)

- Global mineral and chemical maps (MRD-140)

- Global Thermal Inertia Maps (MRD-155)

MRD-137 : Global Boulder Geology Map (MRD-137)

This is a map of the integrated geology of boulders located on the surface of Bennu. The boulder geology map presents the locations and sizes of boulders/rocks across Bennu, in conjunction with diagnostic spectral information and relationship to the geopotential of the body.

Inputs for time-sensitive "Global Boulder Feature Map"

- Global Mosaic @ 21-cm resolution (MRD-121)

- Global Topographic map (MRD-122)

Inputs for long-term science "Global Boulder Geology Map"

- Global Color Ratio Maps (MRD-141)
- Global Reflectance Factor Maps (MRD-154)
- Global Bond Albedo Map (MRD-154)
- Global mineral and chemical maps (MRD-140)
- Global Thermal Inertia Maps (MRD-155)

MRD-138 : Global Regolith Geology Map (MRD-138)

This is a map of the global distribution of deposits or patches of loose material (regolith) on the surface of Bennu, along with evidence for mass movement of regolith.

Inputs for Global Regolith Feature Map (map of crater material and linear feature material):

Global Mosaic @ 21cm resolution (MRD-121)

Global Topographic Map (MRD-122)

Inputs for Global Regolith Geology Map (long-term science):

Global Slope Map (MRD-126)

Global Space Weathering Map (MRD-542)

Global Mineral and Chemical Maps (MRD-140)

Global Bond Albedo Map (MRD-154)

Global Reflectance Factor Maps (MRD-154)

Global Thermal Inertia Maps (MRD-155)

MRD-139 : Global Linear Features Geology Map (MRD-139)

This is a map of geomorphological features on the surface of Bennu that are not impact craters or boulders and are linear in appearance

Inputs for Global Linear Features Feature Map (map of linear features locations):

Global Mosaic @ 21cm resolution (MRD-121)

Global Topographic Map (MRD-122

Inputs for Global Linear Features Geology Map (long-term science, includes analysis and interpretation):

Global Slope Map (MRD-126)

Global Space Weathering Map (MRD-542)

Global Mineral and Chemical Maps (MRD-140)

Global Bond Albedo Map (MRD-154)

Global Reflectance Factor Maps (MRD-154)

Global Thermal Inertia Maps (MRD-155)

Ability/Availability of the System to Generate Sufficient Observations

Assuming the DRM is executed successfully, the data required to generate the Crater, Boulder, Regolith and Linear Features Geology maps and close out this Level 2 requirement are available and capable of providing the necessary information.

Minimum Success Criteria

The minimum success criterion of this MRD is that each of the Data Products is produced at the accuracy (or length/size scales) described in each MRD.

Observational Requirements

The observations required to identify and map each of these geologic features varies by feature, but is typically a function of image resolution, sun angle and topographic resolution. For each Data Product, the Observational requirements are explained on their Data Product Description page - and are quickly summarized here:

Global Crater Geology Map (MRD-136) - Moderate incidence angle and low emission angle with 5 pixel resolution on each crater OR Topographic data 1/8th crater diameter or 1/20th crater depth.

Global Boulder Geology Map (MRD-137) - Moderate incidence angle and low emission angle with 4 pixel resolution on each boulder OR Topographic data 1/3rd boulder size.

Global Regolith Geology Map (MRD-138) - Imaging resolution superior to 1m (4px) over 80% of Bennu. If MRD-121 is achieved (21cm resolution over 80% of Bennu), then the necessary observations exist to map regolith regions.

Global Linear Features Geology Map (MRD-139) - Minimum imaging resolution of 31cm(4px) required for 80% of the surface with a North and South observing station.

Dependencies by Mission Phase

The geologic map products depend on both the imaging campaign and the topography. Furthermore the capability to map certain features depends on criteria involving both sun angle and imaging resolution, such that a variety of observing stations might be need to achieve successful mapping at required surface coverage. Largely, the geologic mapping is inclusive of nearly all imaging during nearly all mission stages.

Here, the topographic products availability as a function of mission phase:

Mission Phase: Detailed Survey

The distance from the asteroid surface is approximately 5km and data is taken throughout an entire rotation of the asteroid. There are 2 image cubes per every 3rd slew N and S and a total of 124 N-to-S or S-to-N slews. Each slew involves a rotation of the asteroid's surface by 2.9 ° over a period of 127 sec. Each slew moves the +Z axis of the S/C over an angle of 6.4 ° from N to S or S to N. During every 3rd 127-sec period, 10 images will be acquired, 2 for each of the 5 filters (4 color and 1 clear). The S/C is largely station-keeping during this period, nadir-pointed at the asteroid, or the spacecraft is moving slightly in a N-S direction, depending on what's easier. The asteroid will be observed over a full rotation of 4.39 hours for a total of 430 images (42 slews by 10 images plus 10 for calibration). This same campaign will occur at local times of local noon, 3 and 6 pm and 6 and 9 am, for a total of 2150 possible images. An extra 226 images each will be acquired at the high-phase angle stations of 3 am and 9 pm for a total of 2602 images. This spacing allows an asteroid rotation displacement of no more than 10 ° between every image set.

Data Products Per Mission Phase

Detailed survey is scheduled to being (DRM Rev C 1.3) on 1/13/2019, ending 3/13/2019. The data used for these geologic mapping products is processed by IPWG and delivered to RDWG through the SPOC as part of Global Mosaic @ 21-cm resolution (MRD-121). The photometrically uncorrected global mosaic with Polycam will be available as early as 1/28/2019, which will be adequate for preliminary mapping and/or mapping of large features. The photometrically corrected global mosaic will be delivered 3/18/2019.

One key interface between IPWG and RDWG is database of identified Boulders that will be generated and populated by IPWG using a variety of resources (hand counting, automated counting, and citizen science efforts in CosmoQuest). The responsibility to identify these features is that of IPWG under MRD-121, but the effort of turning the Boulder Database into Boulder Feature Map and Boulder Geology Map will be done by RDWG. The database will be a postGIS database, and the main effort of RDWG will be to turn the database into ShapeFile format.

Overview of Data Processing Products and Timeline

a) Images and image mosaics: The ground data system image pipeline will correct images for bias, shutter smear, dark current and flat fields. Dead and noisy pixels, as well as cosmic ray blemishes, will be corrected. All processed images, as well as notable intermediate results, will be archived in the SPOC Database for convenient access and use. Subsequent processing will include the application of geometric and radiometric calibration files, informed by the camera position, solar illumination and attitude information provided by the SPK, CK, IK, SCLK, PcK and FK kernels. Optical distortion, spectral responsivity, radiometric correction and assignment of pixel pointing will be accomplished in this phase. Again, all images, including intermediate results, are archived in the SPOC Database. Using SPICE data provided by the mission and updated by SPC processing, we will correct each pixel for the photometric function (viewing geometry) and tile the image data into image mosaics.

b) Topographic maps: Extract the relief information from these maps and assign them to individual pixels in each image and to each image mosaic. The OBJ shape files only contain facet and vertices information. The Ancillary map file format include a list of facet numbers, latitude, longitude and radius. Thus topography can be correlated with the OBJ shape model via interpolation of latitude and longitude to particular facets.

c) Feature Maps: To avoid confusion caused by shadow variations from the E and W imaging positions we will initially use only the data from either the Eastern or Western Hemisphere. These maps will be analyzed visually using a tool that allows the analyst to mark the positions and shapes of boulders, craters, regolith areas and linear features (JAsteroid or SBMAT). The analysts will be members of the OSIRIS-REx mission with the possible augmentation of members of a citizen science program recruited and trained to help with this type of analysis. The output data formats are ShapeFile format, which is an ESRI standard in the geologic mapping community.

d) Craters database: Currently the most reliable method to identify craters, particularly craters on asteroids, is manually (by human visual inspection). Typically, images are displayed on a computer screen, and the user has the ability to adjust the magnification and brightness/contrast (see below), and mark crater location, diameter, depth, and other key morphological features in an excel/text file. This will likely be done as part of creating the Feature maps and the results will be stored in a database of crater information.

e) Boulders database: Currently the most reliable method to identify boulders on an irregular object is by manual inspection. A typical implementation of the measurement effort is to display images on a computer screen, with the ability to adjust magnification and brightness/contrast (see below), and mark boulder location, aspect ratio, and other key morphological features in an excel/text file. This will likely be done as part of creating the Feature maps and the results will be stored in a database or boulder information. The responsibility to populate the Boulder database is that of IPWG under MRD-121.

The timeline to follow these processes to generate each of the four Data Products depends heavily on the number of features per map. The overhead to ingest the relevant data products, correlate topography and imaging on the 3D shape model, and simply inspect the images for features should be a matter of a few days to 1 week for each data product. Using one of the standard tools - Small Body Mapping Tool - RDWG-lead Walsh was able to outline <10 regions, draw <10 circles around craters, mark <10 boulders in under 1 hour. A large number of features may require multiple workers from RDWG to collaborate to map all relevant features in <2 week timescales.

Provenance of Algorithms, Software and Techniques

The surface geology of Bennu will be characterized through various remote sensing campaigns throughout the mission. Each of the Data Products responding to MRDs 136,137,138,139 will be made in two stages.

Feature Maps: At the end of Detailed Survey a "Feature Map" is produced indicating the location of each of these geologic features on Bennu. The location and basic physical properties of these geologic features are important for generation of the Safety Map and Science Value Map and must be distributed at this stage of the mission. The observational requirements to detect and map each of the features is described in each Data Product Description. The Feature Maps do not contain geologic interpretation, and for each of the listed Data Products rely only on:

Global Mosaic @ 21-cm resolution (MRD-121)

Global Topographic Map (MRD-122) .

The detailed process of generating each data product is described in each Data Product Description, linked above.

Geologic Maps: The long-term science product for each of these mapped geologic features is a "Geologic Map" that includes analysis and geologic interpretation and that also incorporates compositional maps. These products are not distributed to other top maps, rather they inform the long-term science Global Geologic Map.

Analysis and verification methods:

Most Verification and Analysis relates to the calculations listed above defining sun angle and resolution limitations for detection of each Geologic feature. The analysis and verification that the sun-angles and image resolutions (or spot-sizes) is done under the Imaging MRDs, in particular MRD-121 and 122. We find that if these MRDs are achieved then the MRDs here will also be satisfied.

The actual production of the Map Products was tested in RDWG as part of a code development effort to generate Sampleability Maps. This effort led to ingestion of Ancillary FITS files and simple cylindrical Hazard Maps (121) from IPWG and the complete generation of a Sampleability Map. The same toolset will be used here to generate maps (see some code at the Map-Making Toolkit Software page.

Similarly, RDWG exercised the Small Body Mapping Tool, to verify that geologic mapping could be done with this tool. This process was successful and the times for mapping and data sizes were reported in the OSIRIS-REx Regolith Development Derived Data Product Software Interface Specification and in the Data Product Descriptions.

During operations verification efforts will be as follows.

a) Image data: will be assessed using standard data quality checks.

b) Image mosaics: will be assessed visually to ensure the images are aligned smoothly at the image boundaries.

c) Topographic maps: will be assessed visually to ensure the images are aligned smoothly at the image boundaries.

d) Feature maps: will be assessed visually to ensure the images are aligned smoothly at the image boundaries.

e) Craters database: we will perform an independent assessment of the crater population in restricted regions of the asteroid.

f) Boulders database: we will perform an independent assessment of the boulder population as determined as IPWG in restricted regions of the asteroid. This will be on-going as we combine boulder information from multiple sources (automated techniques and citizen science).

Software Development in Support of RDWG Geology Science

Image data and Image mosaics are processed and created with a software package capable of image processing such as the mission produced map tools in C (using the fitsio package). RDWG lead Walsh has also produced python packages that can ingest and manipulate Ancillary Fits formats (to interpolate or sub-sample regions for example - producing a standard set of maps on the same resolution shape model). This utilizes the satrapy package, which uses similar fitsio libraries as used for the mission packages.

Topographic maps are produced in ALTWG, and delivered in the mission standard Maps format, readable by JAsteroid and SBMT. These tools will be used to process and view image data, enable the display and annotation of individual and mosaicked images and measure the crater population.

The software to identify boulders, craters, regolith regions and linear features on the maps, JAsteroid and SBMT, both have the ability to display images on a computer screen, with the ability to adjust magnification and brightness/contrast, and mark feature locations, aspect ratios, and other key morphological features. These platforms have been used in the past to map craters on the moon and boulders for various space missions.

Existing or Potential Liens

Lien-VIS-01- These maps will be analyzed visually using a tool that allows the analyst to mark the positions and shapes of boulders, crates, regolith areas and linear features (JAsteroid or SBMT)

SPOC Requirements

Host and transfer image and topographic data and maps.

External Interfaces

None.

Summary and Conclusions

The production of Data Products to satisfy MRDs 136, 137, 138 and 139 will produce both Feature Maps and Geology Maps - the former indicates the location and basic physical properties of different geologic features, and the latter includes geologic interpretation drawn from a larger set of observational data. The Feature Maps are done after Detailed Survey and distributed within the mission for various purposes. RDWG testing suggests that the time required to accomplish this should be under 2 weeks, and can be accomplished with JAsteroid and SBMT and Ancillary programs and scripts to manipulate Topographic/Imaging/Other data.

# Requirements for Topographic Products

- Science
  - Requirements remain unchanged since CSR
  - Requirements defined by map resolution with accuracies and precision on the order of, or better than the ground sample distance (resolution) and timing to support creation of site selection products

| | Ground Sample Distance | Accuracy | Vertical Precision | Horizonal Relative Accuracy | Product source and timing |
|---|---|---|---|---|---|
| **Sci 100cm** | <100cm | <100cm | <100cm | <100cm | SPC – PreSurvey/Orb A<br>OLA –Detailed survey |
| **Sci 5 cm** | <5cm | <100cm | <5cm | <5cm | SPC-Detailed Survey<br>OLA-Orb B/Recon |
| **Sci tilt 32 cm** | <32cm | <100cm | <4cm | <32cm | Detailed Survey<br>OLA-Orb B |

# Science Topographic Map Deliveries

- 1m (actually ~75-cm) shape model and related products delivered 1/11/19 (from SPC)
- 35 cm  DTMs and tilt deliver 2/5/19 (from SPC)
- 5 cm DTMS deliver 5/9/19 for at least the two final sampling sites. (Combined SPC/OLA)