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1. **Nature:** R = Report, P = Prototype, D = Demonstrator, O = Other

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Executive Summary / Abstract:

Here, we describe the training materials that have thus far been assembled for lithostratigraphic mapping. In particular, we describe the contents of the data packages we assembled, as an example of the basic types of data that should be provided in training packages. We also discuss examples of higher-level data products that are useful for special applications beyond the production of a basic lithostratigraphic map. We briefly introduce each of the three training areas that were selected on the Moon, Mars, and Mercury to represent a range of geological processes and features on those planetary bodies. Finally, we provide an outlook for the preparation of training packages for landing site analysis and selection.

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1) Background and Rationale

One of the major goals of the GMAP project is the creation of geological mapping training materials that are easy to access and use, that build on the work done by the PLANMAP project. Thus, we have worked to compile and create documentation and references related to both theoretical and technical aspects of geological mapping. One positive result of the need to move the PLANMAP and GMAP Winter Schools online is that many of the lectures, tutorials, and exercises are recorded, which means that they can be viewed by new students at any time. The need to disseminate the Winter School materials online also supported the generation of online data access structures that may have also not been developed for in-person training.

A particular focus in this Deliverable is the preparation of dataset packages for the geological mapping exercises we developed. Modern planetary geological mapping requires not only an understanding of geological principles, but also the preparation of diverse datasets for import into a geographic information system. Because the preparation of the data itself requires a certain level of expertise, we generated data packages for specific areas on terrestrial planets to simplify the training of new mappers in planetary geological mapping principles.

Here, we describe the training materials that have thus far been assembled for lithostratigraphic mapping. In particular, we describe the contents of the data packages we assembled, as an example of the basic types of data that should be provided in training packages. We also discuss examples of higher-level data products that are useful for special applications beyond the production of a basic lithostratigraphic map.

2) Types of GMAP Training Materials

a) Documentation and References

The documentation being generated for the GMAP project can be viewed at the project website (www.europlanet-gmap.eu/about-gmap/deliverables/). These materials expand upon deliverables generated for the PLANMAP project (wiki.planmap.eu/public/Deliverables_8193472.html). In particular, D2.3 Update of Mapping Standards from the Planmap project serves as a basic primer on standards and approaches to geological mapping, and contains references to the primary literature on the subject. In particular, the mapping standards are based on existing USGS mapping standards (planetarymapping.wr.usgs.gov/Page/view/Guidelines). The PLANMAP project extended the USGS recommendations to special map types, in addition to providing examples of the application of the USGS standards to different planetary bodies.

b) Recordings of Lectures and Tutorials

In the scope of the Planmap Winter School we created a well-rounded course consisting of recorded lectures and tutorials on various aspects of geological mapping and the creation of planetary maps. These recordings can be accessed via the links provided in Table 1 or by registering at planetarymapping.eu. In the table we sort the videos into categories and give a short description of the content of each recording. The three major categories: science, data, or software, define the general focus of the recording. Science recordings include descriptions of the geological background and evolution of planetary bodies, as well as the interpretation of surface data. The data category introduces different data types that are used to create planetary maps and how to find the right data for specific purposes. The software category collects recordings relevant to software for creating maps, cross-sections and map layouts.

Table 1: Recordings of Lectures and Tutorials

Video Title	Category	Short Description
Welcome and Introduction to geological maps https://youtu.be/LK7bxS4mtLU	Science	History and evolution of geological maps on earth and different planetary bodies
Geological things from other Worlds https://youtu.be/A7g76WN93Q8	Science	General introduction to the evolution of the solar system and the geology on the different planetary bodies
Introduction to remote sensing and planetary data https://youtu.be/Vw-fUQSUp9E	Data	Introduction to interpreting satellite image data and overview of planetary data repositories
Introduction to spectral data https://youtu.be/hkBTPNbSAgE	Data	Introduction to different kinds of spectral data and their analysis
Introduction to QGIS https://youtu.be/56UvAHmYnHI	Software	Introduction to working with geographic information systems (gis) on the example of qgis
How to use streaming maps in QGIS https://youtu.be/PKsldfxpXcs	Software	How to access and use streaming maps in qgis
Practice with Mappy, Q&A https://youtu.be/MZMapDfoAVc	Software	Introduction to mappy, the mapping tool in qgis.

Video Title	Category	Short Description
Morphology and Geological Mapping on the Moon https://youtu.be/mvv1yMKdnLs	Science	Introduction to surface features observable in satellite images on the Moon and measuring timing of geological surface processes
Open Source Tools for crater counting https://youtu.be/yg_XEa8lks0	Software	Introduction to software to determine ages of geological units
Mercury surface morphology https://youtu.be/WlluVGhemuU	Science	Introduction to Mercury's surface morphology, explaining different landforms and geological processes
Mercury surface composition https://youtu.be/ZJ2mt7AINSY	Science	Chemical variations on Mercury's surface as seen in spectral data
Mercury spectral analysis https://youtu.be/ZJ2mt7AINSY	Science	Introduction in the production of higher-level spectral data from Messenger data
Mapping Mars Sedimentary Deposits https://youtu.be/uobNmAbUIVk	Science	Introduction into the morphology and categorization of Mars sedimentary deposits and their stratigraphy
Spectral data in the sedimentary deposits of Mars https://youtu.be/8S-NCZbrgqw	Science	Spectral distinction of Martian sedimentary deposits and identifying minerals
The origin of chaotic terrains https://youtu.be/GhtpvAnn8CY	Science	Geological interpretation of the origin of chaotic terrains
Creating geological cross sections https://youtu.be/j4tsfVTr5q0	Software	History of geological cross-sections and overview of use for cross-sections
Stratigrapc column and correlation https://youtu.be/vPIXlOD6XUU	Science	Visualization lateral and vertical relations among units and detect missing times and examples of different visualization methods

Video Title	Category	Short Description
Cross-section creation in QGIS and InkScape https://youtu.be/wpqR9ycUdJs	Software	Process explanation on how to create cross sections from an existing geological map using qgis and inkscape
History of planetary cartography and map layout https://youtu.be/AFtAR1CNHpg	Science	Use and importance of planetary cartography map layout
QGIS Map Layout Tutorial https://youtu.be/AFtAR1CNHpg	Software	Creating a map layout for a geological map created in qgis

c) Data Packages for Training Areas

Data Packages for training areas are currently mostly only available on the internal cloud drive accessible via registration at planetarymapping.eu. However, they are being prepared and uploaded for easier community access at: https://zenodo.org/communities/gmap (see also, Table 2).

Table 2: Data Packages for Training Areas

Data Package Title, Link, DOI	Short Description
GMAP - QGIS Training Material: Ingenii Basin (Moon) https://zenodo.org/record/6675775#.YrWMuuxBxhE 10.5281/zenodo.6675775	This dataset is part of the Geology and Planetary Mapping Winter School 2022 featuring Ingenii Basin as a study area. Ingenii Basin is located on the lunar farside centered at 33.7°S 163.5°E within the South Pole-Aitken basin.
GMAP - QGIS Training Material: Aram Chaos (Mars) https://zenodo.org/record/6698504#.YrnSI-xBxhF 10.5281/zenodo.6698504	Aram Chaos is a martian crater characterized by the presence of Chaotic Terrains forming mesas and knobs, associated with the outflow channel of Ares Vallis, centered at 2.6°N 21.5°W.
GMAP - QGIS Training Material: Beagle Rupes (Mercury)	Beagle Rupes is a lobate scarp on Mercury, centered at 1.9°S 258.89°W.

Data Package Title, Link, DOI	Short Description
https://zenodo.org/record/6695546#.Yrns2uxBxhE 10.5281/zenodo.6695546	

3) Contents of Standard Lithostratigraphy Training Packages

a) Basemaps

The quantity and quality of planetary data are increasing dramatically so that many different datasets with different resolutions and coverage can be obtained for individual planetary bodies. This increases the possibility to perform observations for a single region at different scales or also temporally (e.g., muted.wwu.de, quickmap.lroc.asu.edu/). This capability provides an unprecedented modern look at the geology of planetary bodies. At the same time, it provides potential challenges in data processing, map projecting, and also the application of consistent mapping techniques to ensure that map details are consistent throughout the whole area.

To provide the widest possible range of resolution and maintain a regional view of the mapping area of interest, and to aid in learning how to maintain mapping consistency across a map, the basic sets of maps included in a project typically cover a range of resolutions and cover an area that extends beyond the area to be mapped. Such datasets are referred to as basemaps, and tend to be low to medium resolution visible wavelength images with solar incidence angles of about 60 to 80 degrees (e.g., Lunar Reconnaissance Orbiter Wide Angle Camera mosaic, 100 meters/pixel; or Kaguya SELENE Terrain Camera orthomosaic, 7 meters/pixel resolution).

For the purposes of the GMAP training activities, the goal is to teach how to (1) identify and describe the geomorphological and structural units present in the mapping area, (2) define the contacts and positions of the features, (3) determine which standards to use for the artwork, (4) select a map scale accordingly, and (5) keep this scale consistent throughout the study area.

All the basemaps in the training materials are provided in a GIS-ready format, either directly available from the PDS or processed using the standard pipeline in ISIS (Integrated Software for Imagers and Spectrometers) (Laura et al., 2022).

b) Digital Terrain Models

Analogous to the image data, the availability of DTMs has also increased dramatically in the last years, particularly for some planetary bodies (i.e., Moon, Mars). In this case, the data provided in the data package are limited to the ones necessary/useful for the purpose of making a geomorphological map. For example, DTMs can help define unit boundaries and provide information about surface roughness. DEMs are also important for generating geological sections and perspective sketches. Typically a lower resolution DTM is adequate to provide the details necessary for a geomorphological map at a larger scale. Thus, a product such as the Lunar Reconnaissance Orbiter Wide Angle Camera DTM with 100 meter/pixel resolution is typically used as a base map. Higher resolution DTMs quickly increase the size of the GIS project, but do not necessarily improve the basis for the mapping, and may even complicate the execution of the map by providing too much detail.

All the DTM layers for the training materials are provided in GIS-ready format, using either data downloaded from the PDS or processed using ISIS and the NASA Ames Stereo Pipeline (ASP) (Beyer et al., 2018).

c) Spectral / Compositional Data

Spectral and compositional data can be added to a mapping project as an optional secondary basemap for subdividing geomorphological units into geological or compositional units. For example, the Clementine color ratio map is often used as a basic compositional map to allow the separation of different lunar mare basalts and other lunar rock types. In this case, however, the spectral data are used to refine an existing geomorphological map, rather than as a primary base map. More information about the integration of spectral data into geomorphological maps can be found as deliverables for the PLANMAP project (wiki.planmap.eu/public/Deliverables_8193472.html).

d) Higher-level Products

Higher level products are derived from basic and standard datasets to provide specific special kinds of information for special purposes. Types of higher level products include hillshade, slope, terrain roughness, optical maturity, rock abundance, and regolith property maps. Beyond regular geological mapping projects that require a minimum of base maps, special projects may require the addition of these higher-level data products to allow the investigation of additional questions or to provide input for mission planning. One prime example of a project that requires higher-level products is the analysis of landing sites (see section 5).

4) Selection of Training Areas

The selected training areas are selected to meet three basic constraints: (1) good data coverage, including different datasets to allow multi-scale observations; (2) good geological variety, including different morphologies and deposits, and (3) an areal distribution of the features that allow both meaningful mapping by (a) a single person in a portion of the area, or (b) collaborative mapping by different people or groups of people who concentrate in different parts and then merge the results. The training areas on different planets are chosen to also show geological units and features that are representative of geological processes on these bodies.

5) Examples of Training Packages

a) Ingenii Basin, Moon

Ingenii Basin is located on the lunar farside centered at 33.7°S 163.5°E within the South Pole-Aitken basin. The floor of the 282 km diameter Ingenii Basin is filled with mare basalt deposits that are overprinted by lunar swirls, large craters, secondary crater chains, and secondary crater clusters. We compiled a beginner to intermediate-level training package for the area (Pöhler et al., 2022). The package includes the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) global mosaic (Speyerer et al., 2011) as a basemap, the Lunar Orbiter Laser Altimeter (LOLA) and SELenological and Engineering Explorer (SELENE) Kaguya merged lunar digital elevation model (DEM) (Barker et al., 2016) and spectral data in the form of a clementine Ultraviolet/Visible (UVVIS) warped color ratio mosaic (Lucey et al., 2000). The data is cut to the area of interest and a training project is set up for QGIS.

The training package is designed as a group exercise with four adjacent tiles covering the entirety of Ingenii basin. For beginners the aim is to create a large-scale map of the area, wherein the basin rim, floor, and mare basalt unit are distinguished, as well as smaller craters that occur across the area. The stratigraphic relationships of the units can then be defined based on superposition, degradation state, and embayment. For intermediate mappers, the training exercise can be extended to include the marking of the lunar swirls, as well as selection of potential areas for crater size-frequency distribution measurements for determining absolute ages for an absolute stratigraphy.

Detailed instructions on the mapping exercise are given in this video: https://youtu.be/t6Hyv3E7Jgw.

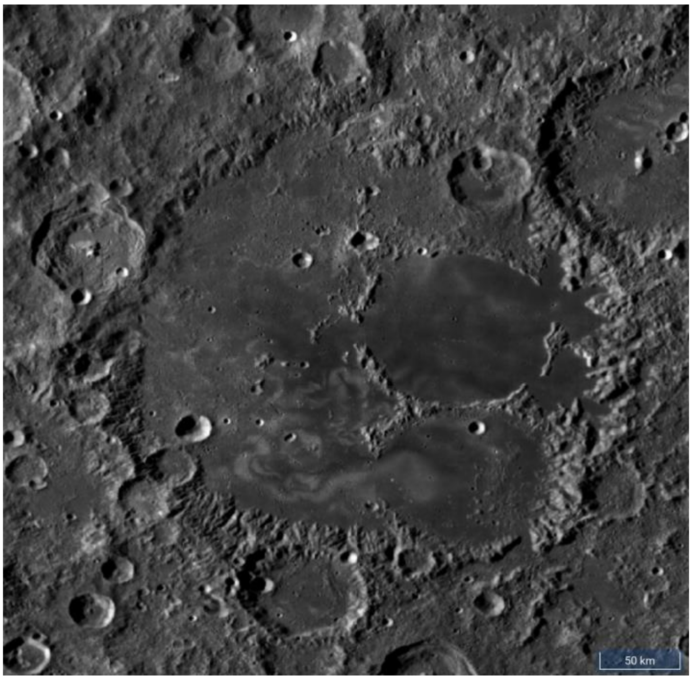

Figure 1: *Ingenii Basin, Moon features multiple large craters within a basin with subsequent mare basalt infill and surficial features such as swirls and secondary craters [LROC WAC DTM].*

b) Aram Chaos, Mars

Aram Chaos (centered 2.7°N/21.2°E) was selected as a training area for Mars because it meets all the criteria for a training area, and also exhibits geological settings that are unique to Mars. Aram Chaos is a more than 250 km large crater characterized by the presence of Chaotic Terrains forming mesas and knobs, associated with the outflow channel of Ares Vallis. The Chaotic Terrains are unconformably embayed and locally superposed by some layered hydrate minerals-bearing deposits.

We prepared a training package including a complete HRSC coverage (including images and DEMs) (Neukum et al., 2004; Jaumann et al., 2007) and selected CTX (Malin et al., 2007), HiRISE (McEwen et al., 2007), and CRISM (Murchie et al., 2007) data (Pondrelli, 2022). The area has been divided into 8 tiles, with each one a 'stand alone' area in terms of geology, but at the same time ready for collaborative mapping purposes.

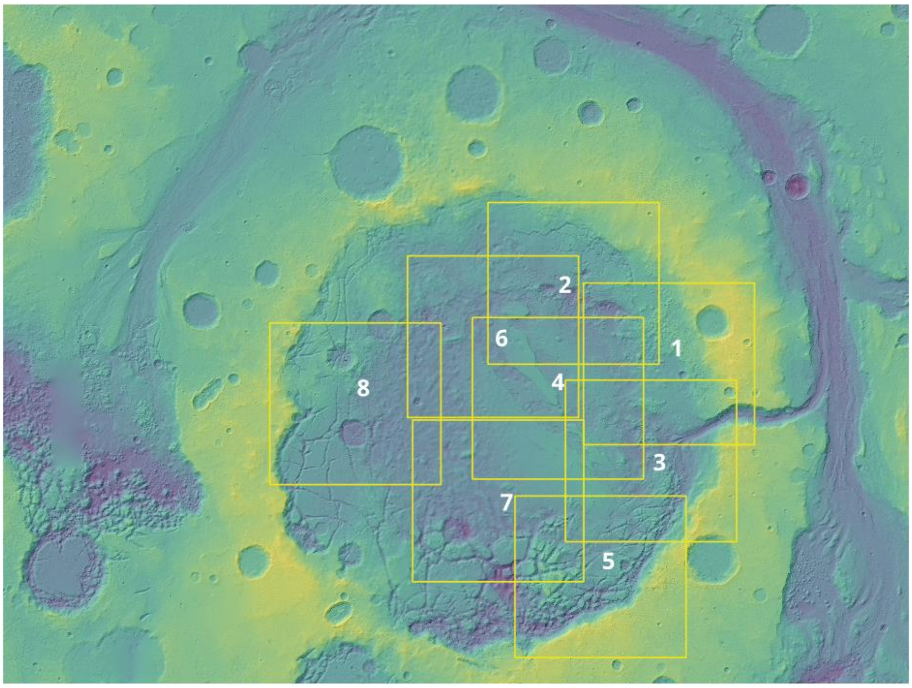

Figure 2: *Aram Chaos, Mars is a 250 km diameter crater exhibiting chaotic terrain, mesas and knobs, associated with the Ares Vallis outflow channel.*

c) Beagle Rupes, Mercury

Beagle Rupes is lobate scarp at Mercury's surface with a length of more than 600km cross-cutting an oval-shaped crater.

We compiled a beginner to intermediate-level training package for the area (Galluzzi, 2022). The package includes several basemaps such as Map Projected Basemap Reduced Data Record (BDR) (Hash et al., 2013a), High-incidence East-illumination Basemap (HIE), Map-projected High-incidence West-illumination (HIW) (Hash et al., 2015a), Map Projected Low-Incidence Angle Basemap Reduced Data Record (LOI) (Hash et al., 2013b), Map Projected Multispectral Reduced Data Record (MDR) Hash et al., 2015b) and digital terrain model (DTM) (Becker et al., 2016). The data is cut to the area of interest and a training project is set up for QGIS.

The training package is designed as a group exercise with four adjacent tiles covering the Beagle Rupes area.

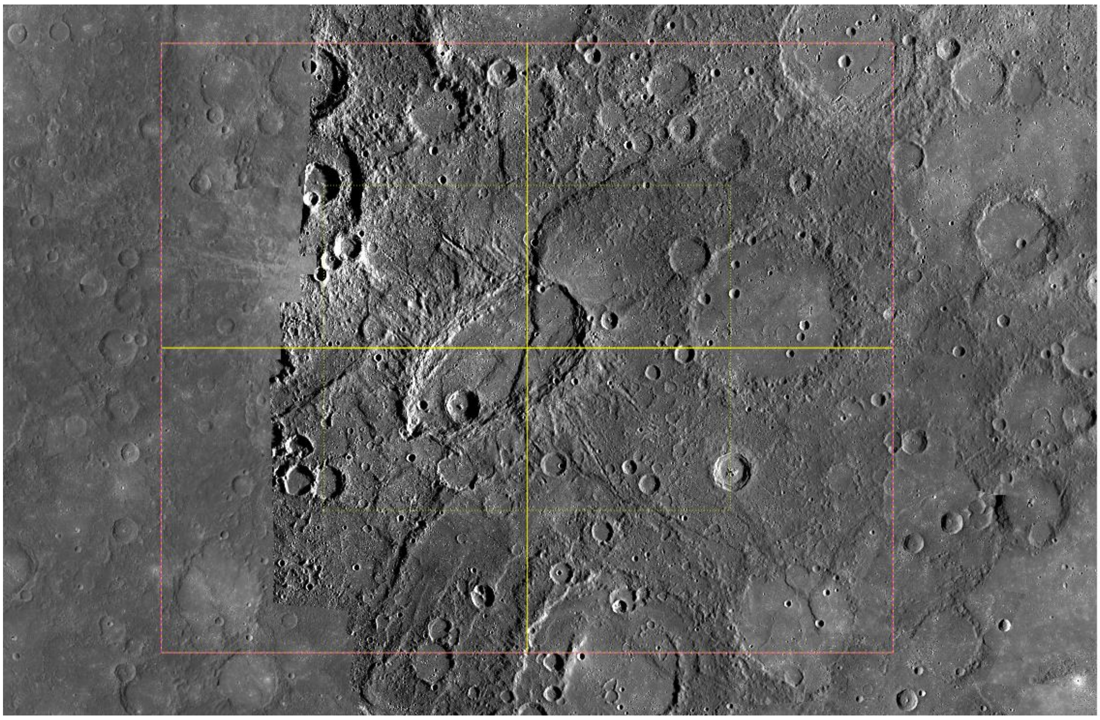

Figure 3: *Beagle Rupes, Mercury is a 600 km long scarp that crosscuts Sveinsdóttir crater.*

6) Development of Landing Site Training Packages

The next training packages that we plan to compile will show the necessary data for the selection of a couple of specific landing site examples on the Moon and Mars. The selection of landing sites requires the evaluation of both science and engineering constraints and thus requires a wider range of basemaps. Building on image data, DTMs, and spectral/compositional data, higher-level products are necessary particularly for assessing potential hazards at the landing sites (see www.europlanet-society.org/wp-content/uploads/2021/09/D8.3.pdf sections 6 and 7 for more details and references).

7) Summary and Outlook

One of the major aims of the GMAP project is to provide information and materials about the production of planetary geological maps from both the scientific and technical sides. Here, we have provided training materials for the open-source geographic information system QGIS, and have compiled documentation, lectures, and tutorials for beginners to intermediate mappers. The next step is to compile a training package for examples of landing sites, which can then be used during the next GMAP workshop. It is expected that additional documentation, lectures, and tutorials will become available, which can be paired with the landing site training packages.

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