ARTICLE TEMPLATE

The Geologic Map of the Cassini Quadrangle on the Moon: Planetary Cartography Between Science, Efficacy and Cartographic Aesthetics

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ARTICLE HISTORY
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1. Introduction

Before humans set foot on the Lunar surface in 1969 during the US Apollo program, the Moon had been investigated in great detail through telescopic observations, and a number of spacecraft sent by the US in the course of the Ranger, Lunar Orbiter and Surveyor programs, and the USSR through their extensive Luna program. Apart from a political motivation, those missions had the purpose of exploring and characterizing the lunar surface and to identify potential landing sites for in-situ exploration by humans.

At that time, maps experienced an extraordinary transition from being solely based on telescopic observation from the Earth to becoming detailed cartographic products based on remote-sensing observation. At this time, maps of the telescope-era became basemaps to be combined with newly acquired data from spacecraft orbit. And at the end of the 1960s, the chapter of Earth-based telescopic cartography has been closed for good (Schimerman, 1973).

One of the many earlier investigations of that decade were the development of hundreds of professional maps ranging in scale from 1:1,000 to 1:10,000,000 and their compilation into chart series and lunar atlases. One of those is the *Lunar Chart (LAC)* series published at a scale of 1:1,000,000 by the US Air Force *Aeronautical Chart and Information Center (ACIC)* for the *National Aeronautics and Space Administration (NASA)* using photographic data collected from various international observatories (Schimerman, 1973). These data allowed surface features on the Moon to be described in terms of relief and reflectance values. Relief was reproduced using an adaptive shading by employing drawing and airbrush techniques to individual feature slopes, and combined with reflectance information from telescopic photography. Absolute topographic information was based on geophysical measurements, while relative topographic information, i.e. relief, was based on photoclinometric data.

The LAC series served as basemaps for a collection of 44 geologic maps of the Moon, known as the *Geologic Atlas of the Moon*. These maps were based on the available sources at the time, including spacecraft observations and thus marking the

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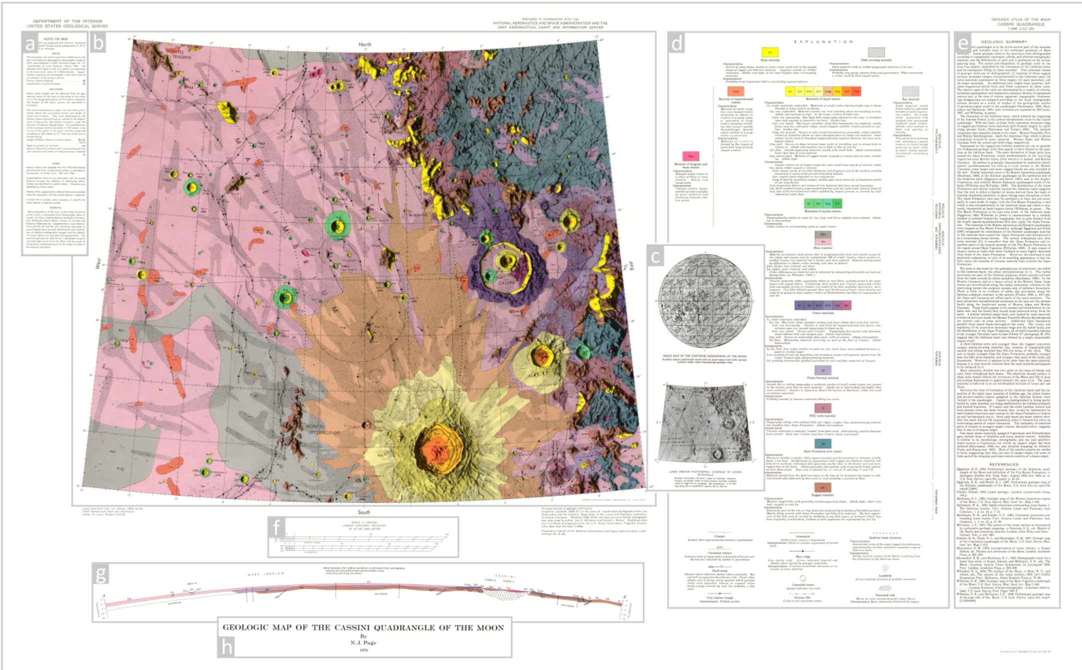

Figure 1. Geologic Map of the Cassini Quadrangle of the Moon (I-666) mapped at a scale of 1:1,000,000 for the United States Geologic Survey Geologic Atlas of the Moon (Page, 1970). Boxes with gray labels refer to elements discussed in the text.

transition from centuries of Earth-based cartography to remote-sensing observation. Besides these maps, a range of larger-scale landing-site maps were published at that time, but notably the geologic work by geologists, cartographers, and illustrators also led to the famous *Geologic Map of the Near Side of the Moon* (Wilhelms, 1971) and the later pivotal publication titled *Geology of the Moon* (Wilhelms, 1987).

In a nutshell, geologic maps in general are special-purpose maps to be used by professionals to reconstruct the history of a region, and to understand the type of rock-forming processes, their lateral and vertical extent, their structural characteristics, their absolute as well as relative age and their specifics, e.g., minerals, and fossils. The concept of a geologic unit on a map encompasses extent, material, process and time within a single map. This complexity of a geologic map is not delivered by stacking a large amount of information on top of each other, but by combining an inherently monothematic map topic with topography and time information in an extremely efficient way.

The map that we describe here is the geologic map of the *Cassini* Quadrangle (I-666) which was crafted by Page (1970) and published as on part of the Geologic Atlas of the Moon in 1970 by the *United States Geological Survey* (see Figs. 1 and 2). The LAC-25 quadrangle map *Cassini* in Lambert Conformal Conic Projection (published in 1966) serves here as basemap that covers parts of the Lunar nearside from 14° W to about 12° E and from 32° to about 49°N (Page, 1970; USAF, 1966), which can be directly observed from the Earth.

This map is representative for those maps published within the *Geologic Atlas* and it marks a piece of history, not only with respect to its topic of Lunar geologic history, but also with respect to the transition that cartography of remote objects has experienced. We would like to investigate the efficacy and beauty of this map in its various facets

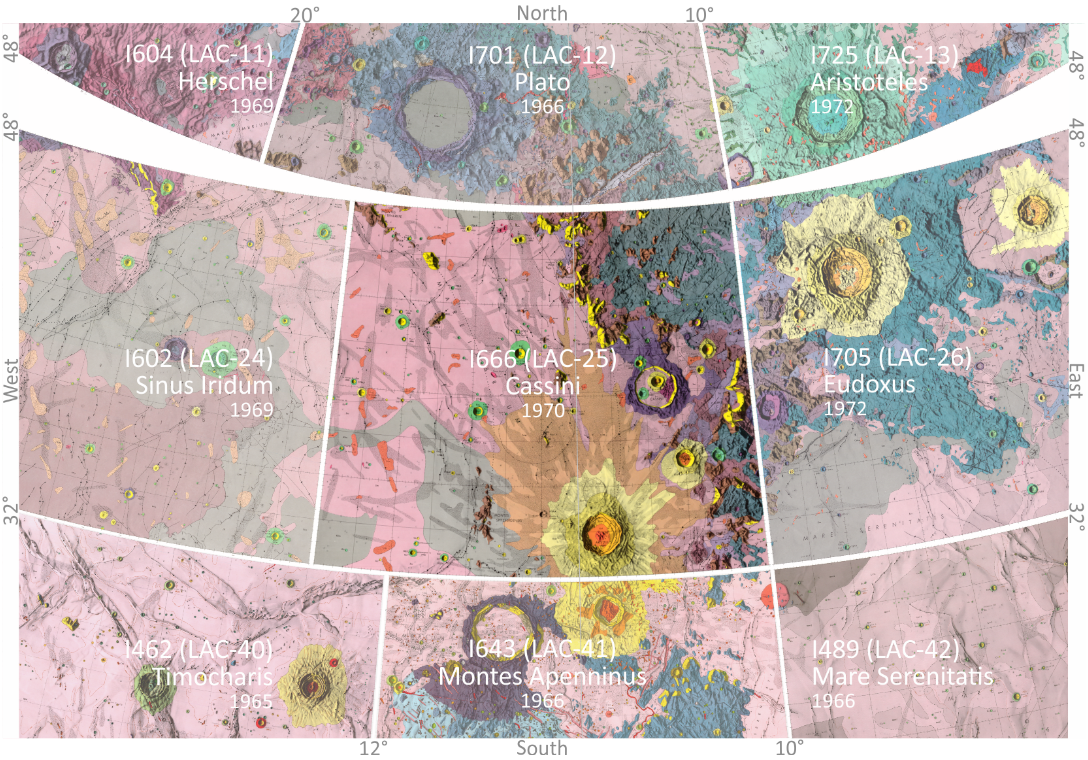

Figure 2. Geologic Map of the Cassini Quadrangle (I-666) of the Moon (Page, 1970) with adjacent quadrangles and their respective publishing dates (all map sheets are available via USGS (2021).

and discuss the question as to how far professional *working* maps with their limited room for creativity can become beautiful products.

2. Design and Function

In order to assess its design and functionality, we break down selected map components (see Fig. 1) and describe the realization of each component and its effect as both, stand-alone qualities, but also within its compositional context (see also Fig. 2 for details).

Technically, the geologic map of the Cassini quadrangle can be classified as a small-scale, qualitative area feature map depicting the geology and geomorphology of the lunar surface as represented by area and line geometries for geologic and geomorphologic units, or structural features, respectively. Individual units are represented through discrete colours representative of different materials and unit ages. The map is focused on the temporal development of a region through the inherent connection between mapped units, geological materials and processes as well as formation times, which describe long-term dynamics. The map should be read as a static map, as a snapshot of geologic history, when it comes to the arrangement of units; but is should be read as dynamic map, when investigating the stratigraphy in a vertical arrangement.

In order to successfully visualize and communicate complexity of reality through a map, a consistent internal graphic structuring is required (Robinson, 1995). With respect to its *horizontal hierarchy*, i.e. the arrangement of cartographic map sheet elements, the map sheet is organized in a (western-centric) reading direction from

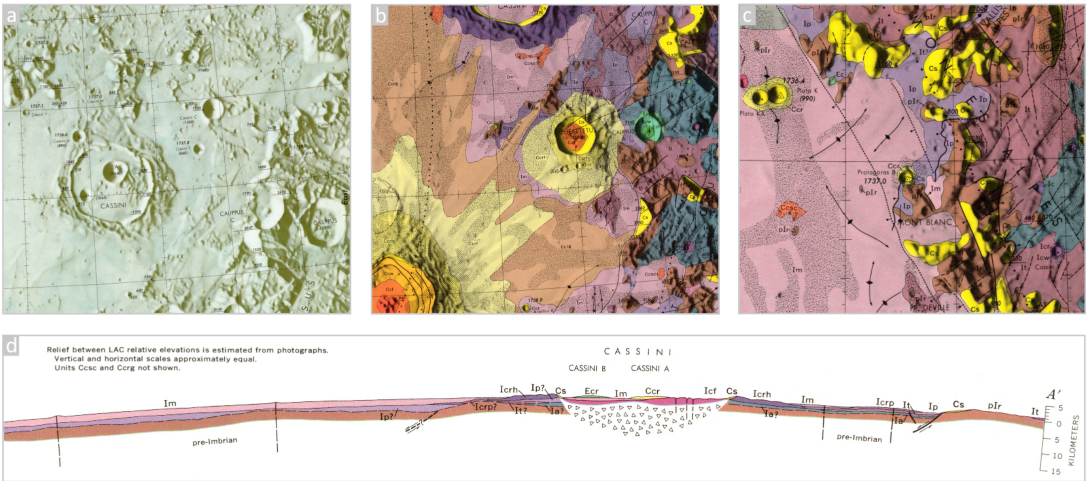

Figure 3. Details from figure 1. [a] shaded relief basemap as originally used in ACIC (1965), [b+c] map details, [d] topographic and geologic profile shown in (Page, 1970).

top left to bottom right (Fig. 1). At the left (Fig. 1a) information with respect to sources and technical implementation for the base map is provided. This description is followed by the actual map (Fig. 1b), its location and index (Fig. 1c), and an extensive legend that is typical for geologic maps (Fig. 1d). A detailed description of the region's geology, is located at the right side (Fig. 1e), which needs to be read in connection with the legend. A geologic cross-profile which is commonly included for geologic maps of the Earth, but which is barely seen for modern planetary maps, was placed at its standard location, below the map (Figs. 1-g, 3-d). The cartographer has chosen to place this profile between map scale information (Fig. 1-f) and title and publishing information (Fig. 1-h) which helps to keep thematic objects together. Despite the text heavy legend and the small fonts, the overall impression does not look overlay crowded.

The *vertical hierarchy* is established through a base map represented through a mixed airbrush shaded relief / reflectance map (Fig. 3a). Geologic units are represented as colored area units delineated by interpreted geologic contacts and are placed as semi-transparent layer on top. Geologic line features, transparent areal features and topographic information are placed on top in the same representation style as they can be considered equally important (Fig. 3b and c). While topographic information is crucial for geologic maps covering the Earth, it is usually not seen in planetary geologic cartography. The reasons for this remain unknown, as topographic information has always been available despite having larger errors in the past due to the selected method to derive it. One reason might have been the fact that the geologic settings for planetary surfaces are relatively simple when compared to tectonically complex regions on the Earth. It is therefore noteworthy, that the existence of relatively densely spaced discrete topographic point information is available for this map (Fig. 3c).

Probably the most dominant impact and effect on the communication of contents in cartographic products is established through the effective use of visual variables. Geologic units as represented by different colours are the first and most pronounced features (Fig. 3b and c). While different colour hues generally refer to different material and age classes, the variation of colour values (intensities) and saturation values refer to subdivisions within each unit. Furthermore, while oldest units are generally presented in subdued hues and lower saturation and lightness values, fresh and younger units show more vibrant colours. Even without knowledge about geologic maps and standards, oldest terrain can be easily separated from young terrain based on the association and the selective property of colour hue (Fig. 1). For units such as the dominant impact crater in the South, the lightness gradient gives an interesting plasticity to the overall shape (Fig. 3b).

Geologic maps often impress because of their rich colors and complex appearance that can become rather overwhelming depending on the geologic history and mapping detail. Due to the predefined and standardized color scale – at least on a small temporal scale – colors do not necessarily correspond very well and cannot provide an aesthetically pleasing experience. And for functionality reasons, that might be good. For the Cassini quadrangle map, the distribution of color hues looks relatively balanced and aesthetically pleasing with a good mixture between subtle and dominant colors. Nonetheless, the map content seems to tilt slightly towards the right due to the selected lunargraphic extent and the color dominance of the map units in the East, which is a bit more pronounced by the map layout with a text-heavy legend on the right-hand side. Through the (likely not planned) empty space on the left of the map sheet, an internal balance could be re-established partially. This map, however, shows the colour dominance on the overall map sheet balance quite well.

For the overall impression from a distance, the font work and labelling plays a minor role. As detail is key in geologic maps, the cartographer tries not to obscure information by too dominant font selection and labeling work. However, clear fonts and well-placed labels (for examples see Fig. 3b) are a crucial aspect to quickly associate units with information from the extensive legend explanations (cf. Hake, 2001). The fonts that have been used for these map sheets can be separated into two groups, map information, legend and summary are represented by classical roman typefaces which are functional to facilitate text reading. Label elements, grid information and nomenclature are represented by sans-serif typefaces which facilitates map reading and clarity. In addition, tracking is used for labels placed across large areas but the label still remains relatively subdued so that it does not dominate the graphic information which is paramount for a map focused on graphic contents.

When comparing the maps published in the *Lunar Geologic Chart Series*, it becomes evident that some of the maps are visually more pleasing than others due to their more fortunate distribution of geologic units as represented by coloured areas on the map. This, however, is due to the selected map sheet section and quadrangle scheme – the scheme for mapping the Moon at 1:1,000,000 on 144 sheets– that will always give some imbalance, not only with respect to the map aesthetics, but also with respect to the scientific contents (see Greeley (1990) for standard quadrangle schemes). This aspect works aesthetically well for this map, not so technically however, as important features are cut.

The Lambert Conformal Conic projection chosen for the northern and southern mid-latitudes is a common and well-established projection used to find a working compromise to maintain shape, length and area to a degree which is tolerable for research applications. For planetary research, maintaining crater diameter sizes as well as their circular shapes are crucial for geologic interpretations, thus the chosen map projection is one of the very few ones that can actually provide this compromise for smaller-scale maps. It might just be the case for map enthusiasts but we believe that the conical map projection adds to the overall pleasant appearance of the map as we are nowadays very much confronted with cylindrical projections and rectangular graticules to make computer processing and map-reading easier, in particular in web mapping.

An aesthetically pleasing map does not have to be a good map if it turns out as unusable for its readership. Geologic maps need to be explored, they are by no means meant to be looked at briefly. Their detail and their hierarchical levels along with their provision of necessary means to reconstruct the history of development in space and time make it a powerful working tool rather than just a quicklook map. Geologic maps are needed to study and understand the local situation with respect to materials, ages and structural characteristics. They are also used to reconstruct how units developed over time to display the picture one can observe today. The Cassini quadrangle map does an outstanding job in providing the map reader with an abundance of information without becoming too overwhelming (for the standard geologic map reader that is). At first sight, the map allows to immediately separate three main units: pink-colored plains, rugged terrain in brown and grayish-green and a fresh yellow crater unit resembling a fried egg, sunny-side up. This map depiction of an impact crater shows several layers of radially extending material as indicated by colors and superimposed areal symbols as separate units. These three main units are already the essentials of what can be expected for the Moon and this topic repeats through all the maps in this series. The chosen colours do achieve a clear separation of differently-aged units and they clearly exploit the selective characteristic of color hue so that associated units can be very well grouped despite spatial separation. They also achieve that older units – as seen in the stratigraphic explanations in the legend at the right – appear with reduced colour value and saturation, while fresher unit appear more vibrant.

At much closer inspection, this map provides a plethora of information on time, as well as vertical and horizontal position and extent, when studied in combination with the legend. As such, this map provides not only an effective but also a visually pleasing window into the geologic history of the Moon.

3. Conclusions

In this contribution we presented a few selected aspects of a geologic map of a region on the Moon, created by geologists and cartographers in the late 1960s and which is in a way representative of the dedication and craftsmanship that have found their way into these early planetary maps. Despite being limited in freedom due to standards and constraints, the cartographer successfully compiled a map product that is not only extremely useful and effective as a working tool for the geologist, but which is also visually pleasing and well designed. Two aspects are a challenge for geologic maps: information density and effective colour separation including labeling, and design of the overall map sheet due to an extremely high density of accompanying thematic text information, and a graphic table, along with map sheet information. The effective association between legend items and map information must be provided at all times and for each unit, as small as it might be. On the other hand, map unit labels are needed due to the rich amount of labels required. Label placement without obscuring geologic information is one of the challenges that the cartographer mastered notably well.

Such a map needs to be studied and worked with in detail, the effort that has gone into this map without having access to digital tools must have been extraordinary. Knowing that another 43 maps have been published in this series, and that many more maps were produced during that time, makes the reader appreciate the dedication of the cartographers, illustrators and geologists, and also value the effort that has gone into planetary exploration and the compilation and re-use of acquired information.

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