Planetary Maps: Visualization and Nomenclature

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Abstract

Planetary maps are powerful tools for the visualization of the formerly unknown planetary surfaces. The appropriate use of visualization and nomenclature is essential for making planetary maps that can be used by both professionals and the general public. This article describes an international mapping project that has produced several maps of the terrestrial planets and the Moon. The maps were published separately, as educational wall maps, and also appeared together in a world atlas. To select the most effective visual tools and nomenclature, we conducted a map reader perception study at the Eötvös Loránd University, Hungary, which is discussed in detail. The second part of the article describes the current system of planetary nomenclature, highlighting some of its problems, with special attention to its localization for bi- or multilingual planetary maps.

Keywords: planetary, Moon, Mars, nomenclature, terminology, place names, perception, visualization

Résumé

Les cartes planétaires sont de puissants outils permettant de visualiser des surfaces planétaires auparavant inconnues. L'emploi adéquat de la visualisation et de la nomenclature est essentiel lors de l'élaboration de cartes planétaires pouvant servir aux professionnels comme au grand public. L'article décrit un projet international de cartographie qui a engendré l'élaboration de plusieurs cartes de planètes telluriques et de la Lune. Les cartes ont été publiées séparément sous forme de cartes murales éducatives et sont regroupées dans un atlas mondial. Pour sélectionner la nomenclature et les outils visuels les plus efficaces, on a mené à l'université Eötvös Loránd, en Hongrie, une étude sur la perception lors de la lecture d'une carte. Cette étude fait l'objet d'une discussion détaillée dans la première partie de l'article. Dans la deuxième partie, on décrit le système actuel de nomenclature planétaire et on souligne certains problèmes qui lui sont associés; une attention spéciale est accordée à la localisation avec les cartes planétaires bilingues ou multilingues.

Mots clés : planétaire, Lune, Mars, nomenclature, terminologie, noms de lieux, perception, visualisation

Introduction

Planetary maps serve several purposes. They are documentations of our discoveries and current knowledge, an everyday tool for the scientific community, and, for the non-experts – the public, interested students, children – they are attractive representations of strange new worlds. Maps of other planetary bodies – especially with landing sites marked – show that humankind has acquired a new territory in its (our) *oikumene*. Every new detail in planetary maps adds a new place to this known world. Today there are about 7.5 million terrestrial place names; about 8700 undersea place names; and about 7000 named features on the surfaces of other planets (NGIS 2005; USGS 2005). This number might appear insignificant, but these names represent all the known *places* beyond our planet. They do not exist in our cultural perception until they are displayed on the map. Planetary maps are the visual catalogue of the places occupied by our scientific knowledge. They show planets as places instead of dots in the sky. They also show, visually and globally, how little and how much the other planets are different from the Earth, in this way demystifying them and, at the same time, highlighting Earth's uniqueness in the known universe.

Planetary maps consist of at least three thematic layers: (1) a base image (photomosaic, shaded relief, colour-coded topography, geology, etc.); (2) a grid, and (3) nomenclature. Our current state of knowledge of about 10 large and numerous smaller planetary surfaces makes it possible to produce more complex, multi-thematic maps that "compress" our knowledge into a single map sheet. For the scientific community, for a specific use, the best maps are large-scale thematic (geologic and computer generated topographic) maps; for the general public, however, small-scale global maps are adequate. These should contain several thematic layers, just as geographic maps do. On the initiative of the Moscow State University for Geodesy and Cartography (MIIGAiK), several groups in Europe are working on a Multilingual Planetary Map Series (Buchroithner 1999; Shingareva, Krasnopevtseva, and Zimbelman 1999; Shingareva and Krasnopevtseva 2001; Shingareva, Krasnopevtseva, and Buchroithner 2002; Shingareva and others 2003; Hargitai 2003; Hargitai, Bérczi, and Shingareva 2005); as a next phase of this project, the Cosmic Materials Space Research Group (CMSRG) of Eötvös Loránd University in Budapest, Hungary, is working on a new multi-layered map series. This group has conducted a survey among students and amateur astronomers about the map series and modified the maps according to the results of the survey. We also gave special mapping tasks to students during regular classes. In this article we summarize how we produce the maps in our series, which thematic layers we use, and what kind of problems we face in producing our *printed* maps. Our goal is to produce not only maps that are attractive and contain the required scientific contents but maps on which both visual and textual elements are easy to understand for the general map reader.

THE RESPONSIBILITY OF THE CARTOGRAPHER

A planetary map is a powerful tool that can manipulate the map reader's view of the mapped planet. This manipulative capacity of the map is well known from terrestrial maps used for political purposes. If the planetary cartographer whose task is to make a map for the general public uses these tools one way – for example, using Latin names, special colour-coding, and geological symbols – this can suggest that the study of the planet is only for scientists; those who are not experts have no chance to understand the nature of the processes and features of that surface. By using the same tools in another way – for example, providing translated nomenclature, rich textual (interpreting) information, and familiar symbols and colours – the map can communicate that the processes and features are not so specialized and can be understood by anybody. This approach also suggests that the same basic processes operate on all planets. In this way, it can even affect the public's or the individual map user's support of space missions; it can bring a planet closer to our everyday geographic experience or even suggest that the planet might be worth visiting. Other maps can communicate the opposite view, creating the mental image of an alien world that we should never consider visiting. It is therefore important that the cartographer be aware of the ways another planetary body can be visualized using the tools of cartography. The basic problem, in this case, is that most planetary maps made for the general public are made not by cartographers but by planetary scientists, designers, or computer software engineers (the same is true of maps made for media use – weather forecast maps, newscast maps, etc.), or a combination of these (of course, USGS maps are an exception, but these are scientific maps, which are not the subject of this article). Thus, these map-makers have to learn the basic rules of cartography if they want to produce good maps, or cartographers have to start working in this field. Another problem is that maps of several planetary bodies are not available in most languages. Even maps of the Moon are absent in many languages, or, at best, only outdated ones can be obtained from libraries. Planetary maps are only easily available in a few widely used languages.

Planetary Maps in World Atlases

If world atlases have a section for other planets, they usually include photos of the planets, diagrams of their orbits, and their interior structure, together with short descriptions and data. Interestingly, the planetary section usually has no maps. Since these atlases are made for the general public, they are not intended for use as tourist or detailed city maps; the inclusion of planetary maps would serve the same educational purpose as map sheets of Antarctica or of the sea floors. A Hungarian publishing company, Topográf, has agreed to include a section of small-scale planetary maps in new editions of its *World Atlas* (Hargitai, Lazányi, and Kereszturi 2003, 2004). For this purpose the CMSRG has started a new series using topographic colour-coded Mercator maps instead of the two-hemisphere hand drawings used in the MIIGAiK-made series. The only exception is the Moon, which is the only planetary body we can actually observe. We used the two-hemisphere hand-drawn map here because it better visualizes the visible surface of the Moon. All these maps use Hungarian nomenclature (see Figure 1). Our goal is to depict other planets the same way we depict our own – as places.

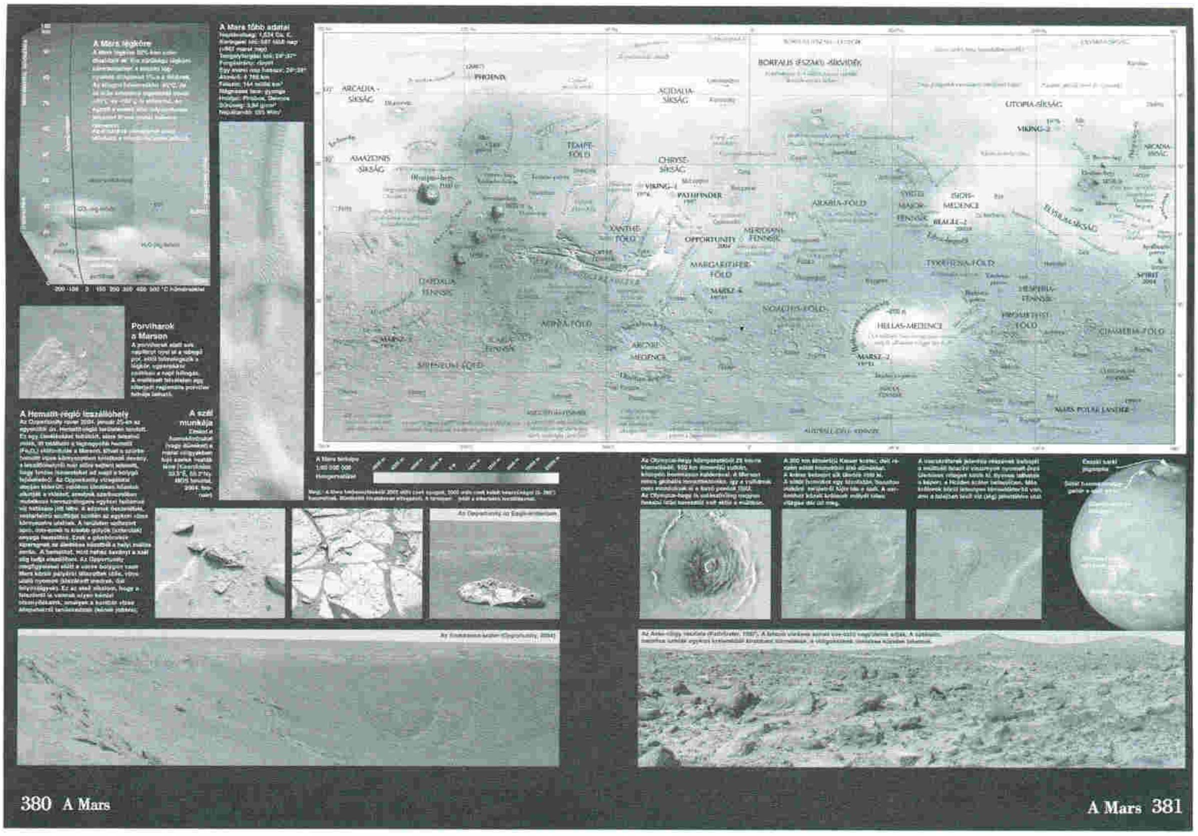


Figure 1. As a result of a compromise, the Astronomy section of this atlas includes both images and planetary maps (Hargitai and others 2003, 2004). The original is in colour.

Planetary Maps: A Reader Perception Study

TEST MAPS

We showed our maps, together with other test maps, to university students, middle school students, and amateur astronomers and asked questions about them. We wanted to know what they understood well and what they could not understand, or not even perceive, such as terms, colours, data, nomenclature, and so on; what they could not find, or missed; what new or surprising information they learned from the maps; and what they generally expected from a planetary map.

We wanted to know whether our Hungarian test nomenclature, whereby the generic parts (descriptive elements, e.g., *Mare*) of the geographic names were translated while the specifics (proper names, e.g., *Imbrium*) were left in their original forms, was more or less helpful in understanding the alien landscape. One departure from our rules was that we used the word *medence* ("basin") to translate the Latin *Planitia* in the case of Argyre, Hellas, and Isidis instead of using the word *síkság* (plains), since this is the tradition form we have already used in oral discussions.

We made a map of Mars from the Mercator series and one of the Moon from the two-hemisphere wall map series (see Figures 2 and 4), one in Hungarian and one in the official International Astronomical Union (IAU) Latin nomenclature.

To obtain information about how map readers could decode the map content, we asked them to describe the geography of Mars or the Moon using only the map. They had very little prior knowledge, or none at all. We asked them where they would land on Mars or the Moon. We also asked, directly, what elements of the map they did not understand and what more they would want to know about Mars or the Moon.

The maps were distributed randomly to 100 middle school students, 100 university students studying communication and media studies, and about 20 amateur astronomers, all in Budapest.

RESULTS OF THE SURVEY: THE PROBLEMS

Nomenclature, terminology

On the translated test map, the specifics all remained unchanged, while the generics were all translated. Thus we used transformation rules with *no exceptions* in order

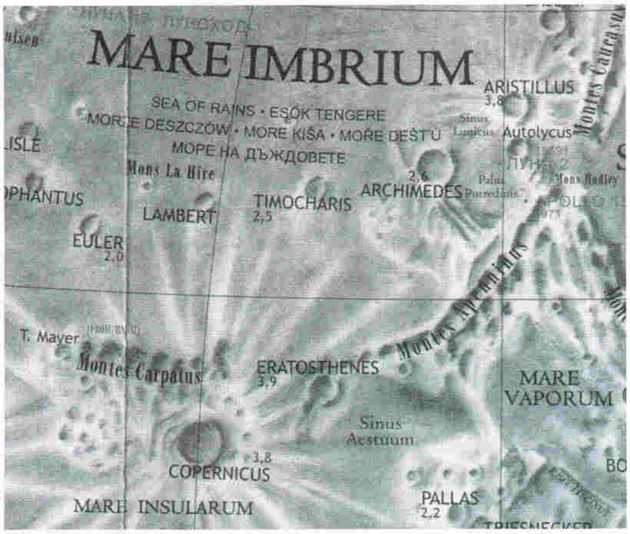


Figure 2. Multilingual map of the Moon (Hargitai and others 2003). The large features are written in large letters in IAU (Latin) form and translated into six other languages (traditional use) in smaller letters. The map also uses multiple scripts, since Russian spacecraft and crater names are written in Cyrillic letters (which most members of the Central European target audience can read). Names of smaller features have not been translated. The original is in colour.

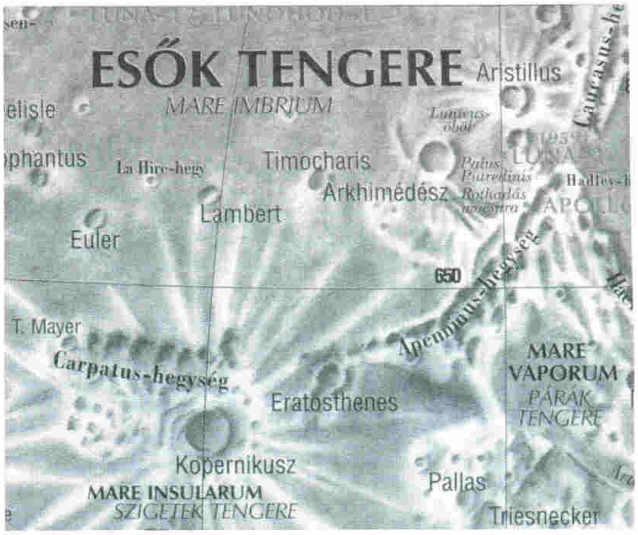


Figure 3. Map of the Moon resulting from the test maps (Hargitai and others 2003, 2004), based on the map shown above. Here the local exonym is shown in large type and the IAU Latin form in smaller type. The names of features other than Mare or Palus are shown only in an experimental standardized way: the specific part is always the same as in the IAU form, but the generic part is always translated. All names originally written in Cyrillic script are transliterated according to the rules of the Hungarian Academy of Sciences (which differ from the English/IAU rules). The widely used Greek personal names are also transcribed according to these rules, while the lesser-known names are kept in their Latinized IAU form. The original is in colour.

to produce a nomenclature from which the original form can easily be re-established.

The results were different in our two focus groups (students and amateur astronomers). The students did not consciously notice the difference between the two versions, but it was clear from their responses to the task "describe the geography of Mars/Moon" that they could "visualize" the landforms using the map with translated nomenclature; while using the IAU nomenclature, on the other hand, they simply copied the Latin terms without understanding the nature of the features to which they refer.

Some members of the amateur astronomer group, who use IAU names on a daily basis in their observation work, disliked our translation procedure, saying that we should have used the traditional forms (exonyms), for instance, Kárpátok instead of Carpatus-hegység for Montes Carpatus. These participants argued that forms that have no tradition, even if they make it easier to find the original form, should be avoided. Other members of this group argued that *both* Latin and Hungarian forms should be used, especially in the case of lunar maria. In the case of Mars, many of them use some of the classical albedo nomenclature, which describes the reflectance of features (dark and bright areas), and only a few feature names are in common use from the "new" nomenclature, which describes topographic features. While they easily accepted the translated names for the less known features (e.g., Isidis-medence for Isidis Planitia), they kept on using the Latin names for the best-known features (e.g., Olympus Mons). This resulted in a mixed nomenclature, which definitely should be avoided.

The other focus group, university and middle school students, had the following problems:

- It was unclear to them what the crater names referred to. Since these names have no descriptive element (the word "crater" is not part of the name), it must be made clear that they refer to craters by means of positioning, with a small dot in the centre of each crater, or in the explanations section.
- The students asked the "traditional" question, "Why are the lunar basins called seas/maria, since they do not contain water?"
- The rays around young lunar craters remained an enigma for these readers, since nothing explained their nature, even though they were clearly visible even in small scale.
- Many missed mountain peak names and peak height data for both Mars and the Moon. This was probably

the most interesting and useful result of the survey. While a large number of individual mountains have names, their highest peaks traditionally lack names and are therefore not included in planetary maps. Locations of peaks were not defined because of the poor resolution of topographic data. Since higher-resolution data can now be extracted from the newly acquired Mars Orbiter Laser Altimeter (MOLA) data, or, in some cases, from Clementine Lunar Laser Altimeter measurements, this may change in the future. Such height data are usually not included in planetary map but, as the survey clearly showed, most map readers "need" it. They also asked for the depth data of some deep basins or maria.
- "Where is the face on Mars?" some asked. This question shows that these readers do want to know the positions of the features whose informal names appear in the popular press and are also used informally by scientists: Inca City (Mars), Cobra Head (Moon), Frozen Ocean (Mars), Si-Si the Cat (Titan), and so on.
- They wanted to know the naming process.
- They asked, "What is the 0 m level in the absence of a sea?" The data of both elevation and 0 longitude needed explanation.

Other problems regarding map reading

- Lunar/Venusian lava channels and Martian valleys of various types, along with other linear features, are usually not shown on planetary maps unless their topography is deep enough to show up in topographic maps. In one case (Hartmann 2003), the position of Marte Vallis is explained in detail in the caption of a map, which states that unfortunately it cannot appear in the topographic map. This is one example where more creative mapping would be needed.
- Many participants mentioned that the bluish colour for low topography was misleading, since blue is traditionally the colour of water on maps. They suggested using a brownish hue instead.
- Many missed the location of ice (caps) on Mars. The polar caps, as in other topographic maps, were first depicted using the colours corresponding to their topographic level. Instead, participants suggested using a bluish white.

Novelties and questions without answers

The following were mentioned as new information the participants learned from the maps:

- Many participants were surprised by the large number of named features and also by the many landing sites.
- Many previously thought that only small height differences existed on Mars. The high volcanoes and deep chasms showed them a new landscape.

The maps did not answer the students' following questions:

- Where is life on Mars?
- What materials are the features composed of?
- How were the features formed?

THE FINAL MAPS

Following the evaluation, we changed the maps. The new maps (see Figures 3 and 5) were shown to 50 university students studying geography to see whether our changes had made them better or not. The results were positive. None of the earlier problems arose, and the new problems were individual (i.e., not repeated by more than one student). The following paragraphs describe why and how we modified the maps.

RESEARCH FOR MAP PRODUCTION

Several feature types have been recognized only in recent years, and the extent of some features is not yet mapped globally, not mapped at all, or mapped and classified differently by different authors. In these cases, the map-maker must use primary resources (scientific articles or images) to find the necessary data for the map.

A clear guide or database of the landform types of our solar system is needed. This is a prerequisite for all maps, since, for the generalization and symbols used in the map, we must previously know what groups and types of features will or can appear on the map. Such a database should contain landforms listed by their geology, morphology, coordinates, IAU names, and other informal names. There is also a need for a catalogue of the historic (or diachronic) terminology in planetary science. During the last few decades the terms applied for certain features have changed, or the same name is now used differently (Almár 2005).

MAPS ARE TO READ, NOT ONLY TO SEE

Our readers found an alien world on the map. Many of the surface forms have no terrestrial parallels, and thus we have no experience to help us imagine them. In the absence of an existing mental representation, the symbols used and the generalization must help readers properly identify the features. Since many of the landforms on other planets do not appear on maps of the Earth, the cartographer has to find a new system of symbols for them. A map that is readable for the "general user" should contain geologic, stratigraphic, albedo, morphologic, topographic, and historic (i.e., landing) information to make the map easier to interpret and understand. Since most planetary maps are very small-scale maps, they can show only a limited variety of features, however, and most of the interesting features are of relatively small size. Carefully selected insets and/or generalization can help to highlight the location of these landforms, such as landslides, layered crater deposits, dark dune spots, small valleys, and calderas, in the case of Mars. Easy interpretation of our symbols is important. Existing geologic symbols can be used only to a limited extent in such a map. A parallel may be contrasts between the

Figure 4. The test map of Mars (detail) with Latin nomenclature. The original is in colour.

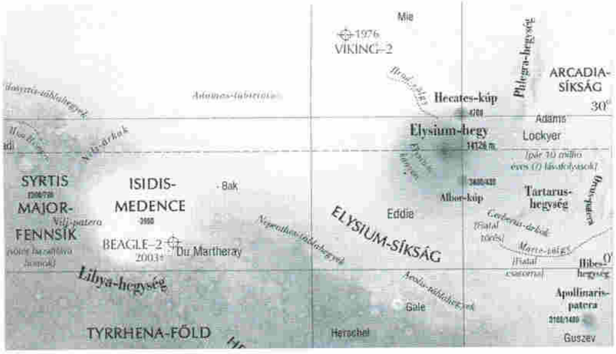


Figure 5. Map of Mars (the same detail as above): first preliminary version after correction with Hungarian nomenclature. Peak and other height data are also shown. The original is in colour.

scientific maps used by meteorologists and the weather maps appearing on TV screens or in newspapers. The latter contain almost the same information but place more stress on design elements.

When speaking about geographic, geologic, climatic, and other phenomena, most people can visualize a typical area where such phenomena can be found on Earth. We all have a cognitive map of landscape types and features, as well as of some place names. This is not true for other planets, however. We are now entering the age when detailed investigation is beginning; photo-maps of other planetary bodies are available on the Internet, and research results and news about features appear regularly in newscasts and newspapers. We believe that in order to form a true cognitive image of other planets and better understand their geologic/climatic systems, people need to connect the known data (textual information, which sometimes includes place names) with visual spatial information (i.e., locations on a map). For this reason, the visual appearance and the accompanying content of maps (colours, nomenclature, symbols, etc.), as well as the environments where these maps are available (as school wall maps, in world atlases, in textbooks, or in electronic form) are crucial factors and will inform people the same way as maps of the Earth have formed the mental picture of our home planet for many centuries, since the world map of Agrippa in the first century BCE. For the cognitive map, the reader needs "hooks," recognizable patterns on the map. On Earth, one such pattern is the contour line of sea level (i.e., outlines of continents and islands) and the blue lines of rivers, both related to hydrology. On other planets this system is absent, so the cartographer must find the best basic pattern from which a planet, or a part of it, can be readily recognized as a "system of places." This is essential if we are to avoid the general belief of "one planet – one landscape," according to which Mars is a desert without topography, as several of the students participating in our survey thought.

MULTILAYERED MAPS

We have tried to look at planetary maps in a new way, as if they were maps of an area on Earth. Terrestrial maps have a tradition hundreds of years old, while modern (topographic) planetary maps have been made for less than half a century (except for the Moon). The surface of the Earth is a complex system of artificial and natural features. Even the simplest maps showing the Earth have several layers of different content (grid, country boundaries, still water bodies, rivers, topography, colouring based on height *and* vegetation, cities, etc.), nomenclature of artificial and natural features (sometimes undersea features), indexes, explanations, scale bars, and so on. On the other hand, most planetary maps have only one such layer (topography or photomap or geology), usually without detailed nomenclature or an index, and very limited explanations that usually address only the colour-coding of heights. Scale bars do regularly appear, even on photos, because it is difficult to estimate the order of magnitude of the area depicted without an indication of scale.

By using the traditional complex system of symbolization for terrestrial maps, we can make planetary maps easier to read. Such a map would be a composite of several thematic layers. The important but very small landscape features would be indicated only by generalized symbols, while others would look more realistic. The map would show selected "hot spots" or "potential scientific tourist attractions", or the proposed "Planetary Parks" (Cockell and Horneck 2004) as insets.

FEATURES OF THE MAPS

Colour-coded topography

We have changed the colours of the deep basins and plains from a darker blue to a lighter yellow. The use of green and blue hues on terrestrial maps denotes not only height but also types of surface cover (vegetation and water respectively). On other planets, because of this second meaning, these colours should be avoided. We used a yellowish-brown hue throughout the map of Mars, altering it according to the topography, to indicate its dry, desert-like characteristic. The light yellowish colour indicating depths on Mars is also associated with light colours of frost as seen in terrestrial observations.

We tried a common colour-coding system relating the same height to the same colour system for all planetary bodies, but it failed to work, since characteristic features of different planets show up in very different scales (e.g., Lunar maria vs. Venusian continents vs. Martian north–south difference). Colour differences should highlight extreme heights in some cases, minimal height differences in others, and on various parts of the same planet (e.g., Lunar mountains vs. maria vs. South Pole–Aitken Basin) or on different planets (e.g., Lunar vs. Martian volcanoes).

Currently we have global topographic maps for Mars (Mars Global Surveyor), the Moon (Clementine), Venus (Magellan), and the Earth (Shuttle Radar) and regional, relative topographic maps from stereo measurements for several other planetary bodies, including Mercury (Cook et al. 1997), Galilean and other icy satellites (Schenk 2001) and Io.

Colour-coded topographic data were *mixed* with actual images of some features with optical, false-colour, radar, and even ephemeral compositional data, including polar ice and sand dune fields.

Shaded relief

In the case of shaded relief maps, the base colour of the shaded relief background gives a characteristic colour to the particular map, which is not necessarily the same hue as the planet's real colour. It is always debatable which exact colour to choose. In shaded relief maps, the base colour can be changed according to geologic data in order to highlight compositional stratigraphic differences such as mare/terra, andesite/basalt/anorthosite, or hematite-rich areas. Using different but harmonious colour variants can indicate various geomorphic landscape types.

Shading

If the planet is shown as two hemispheres, it can be displayed with a subtle limb darkening or other shadowing, making the map look three-dimensional and "realistic."

Albedo

Several kinds of visible albedo features highlight ephemeral phenomena, including wind streaks (indicating wind direction), dark sand-covered areas, latest lava flows, crater rays, dust-devil tracks, and dark dune spots, among others. This wide variety of features usually tells us about the ever-changing processes that are actually shaping the planet's surface. Photographs taken over a period of more than 100 years (Hartmann 2005, 289) and detailed drawings made since the nineteenth century show the changing area of dark sand-covered areas in Syrtis Major. Nilosyrtis and later Nepenthes-Thoth were tails and patches connected to Syrtis Major (Hartmann 2005, 53), but these features have now disappeared. It is questionable whether a map should show these features or not. If we do decide to show them, this can be done using vectoral areal pattern symbols (as for deserts) or individual symbols. For those features that are seen only in certain radar wavelengths that indicate rough surfaces in light colours and smooth ones in dark colours, radar-reflectance images can be used as raw materials.

Ice and frost

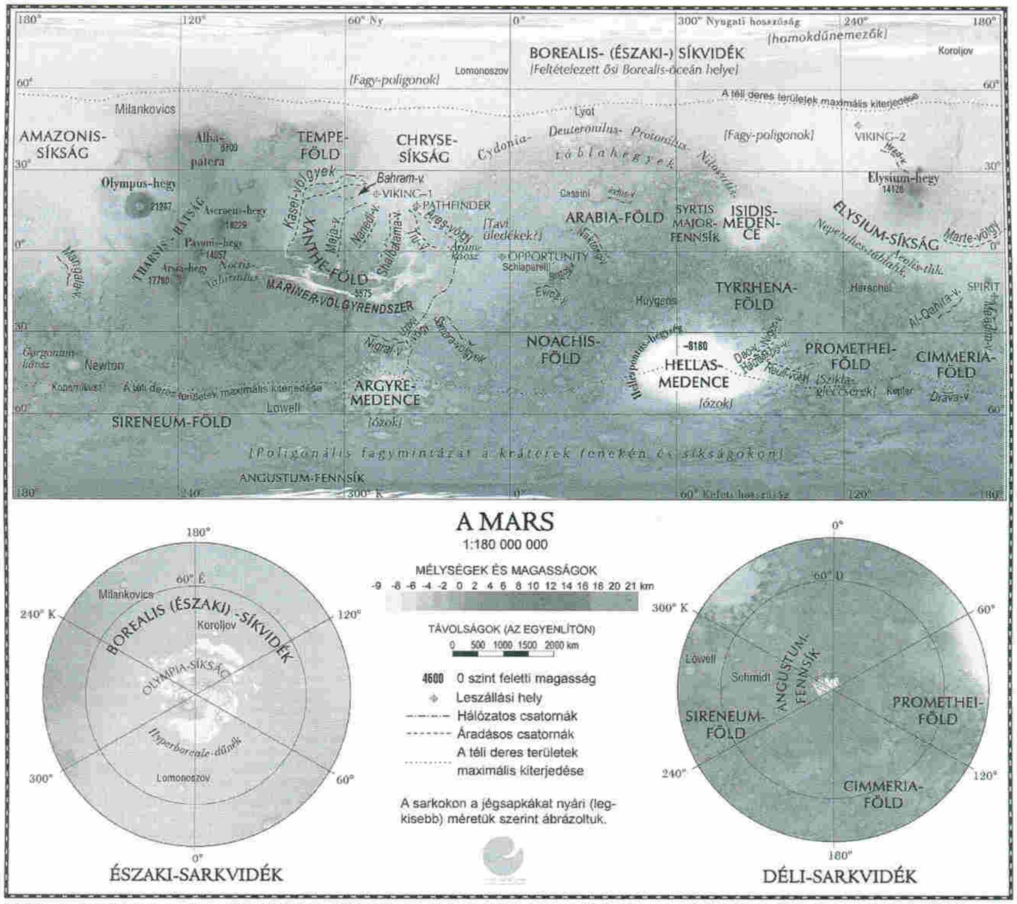
Another ephemeral feature is related to temperature change. Such features can be represented by an extra colour that refers not to their heights but, rather, to polar caps, seasonal extents of polar caps (ephemeral/climatic phenomena), or frost-covered craters. It is good to bear in mind that, on most terrestrial maps, Antarctica and Greenland are shown with their ice covers, which are in fact "ephemeral/volatile" phenomena, rather than the base "silicate continental" topography, while the northern ice cap is usually not shown because its extent changes considerably during the year. We decided to show ice caps as white areas and not according to their topographic height. Since the extent of Martian ice/frost caps varies, it is advisable to show its seasonal borders. We have shown the maximum extent as dotted white lines and the minimum extent as white areas. Other borderline features can also be shown on the maps, such as the estimated boundary of permafrost and possible ocean shorelines on Mars.

Fluvial features

We have shown the linear valley features with lines similar to terrestrial rivers but have used with dotted or dashed lines to differentiate the various outflow/network valley type. We used magenta colour (Figure 6). Locations of possible paleolakes or lacustrine sediment can be shown by symbols. These data should be extracted from scientific papers and databases.

Small-scale features and patterns

For a global map, it can be useful to show features that are too small to depict to scale. Some examples are craters on Venus, polygonal and patterned ground, table mountains, cone/dome fields, valley or crater dunes, pancake volcanoes, rampart ejecta craters, and gullies. These can have their own symbols or can be indicated using short comments placed at the proper location. Our maps use the latter method.



Hengervetület ill. poláris sztereografikus vetület, ideiglenes fordítású magyar névanyaggal. DTM Forrás: Mars Global Surveyor (MGS) Mars Orbiter Laser Altimeter (MOLA) 1998–99.
Térkép: ELTE TTK Kozmikus Anyagokat Vizsgáló Űrkutató Csoport Planetológiai Köre – Mars Society magyar tagozat, 2001—2005. 5., javított, bővített kiadás. http://planetologia.elte.hu

Figure 6. Black-and-white, small-scale, small-size (12-cm) map showing Mars (with Hungarian nomenclature). This map illustrates an article about water and ice on Mars.

On our map of Venus, we used a radar-image-based crater symbol for each larger crater. This means that the apparent sizes of these crater images are larger than the features to which they refer, but they are used as *symbols* for craters, making them clearly visible and characteristic. We also used radar-based details for some crater flows at their true size.

Patterns

Instead of showing each small crater in its place, a "cratered terrain pattern" can be used to show this landscape type, similar to some new terrestrial atlas pages that show various agricultural and vegetation areas. This technique can also show patterned ground, mare terrains, and other landscapes that have a small but repetitive feature.

Artificial features

Landing sites, names of landing/impact sites of spacecraft together with the date of landing, names of rovers, and quantitative data about them were shown using a colour that differs considerably from the general hue of the map.

Extra symbols

We are working on creating new symbols and textures for planetary features. For this work we first catalogued the volcanic, aeolian, fluvial, karst, biogenic, large-scale crustal, tectonic, mass-movement, and impact-feature types (landforms) of all known planetary bodies. Symbols can be based on the Planetary Geology Feature symbols used by USGS (USGS 2004) but must be modified to fit the needs of the general public.

On the map of Venus, we have made a vectoral circle symbol to show coronae that are not very visible on the topographic map. We also used repetitive, vectoral, parallel lines as symbols to show systems of fossae.

Comments

We placed short explanatory texts in the appropriate locations for special phenomena and feature types. This works better than creating too many new symbols. Some of the comments include information related to the climate, geologic history, reflectance, morphology, and age of landforms and man-made objects.

Geographic data
We have shown exact or up-to-date elevation data for the highest peaks and deepest basins. Valley length and depth data and caldera depth data can also be included, as crater rim height data from shadow measurements are included in several Lunar maps. We put more emphasis on surface-area data rather than body diameter because this approach makes the planet more comparable with our terrestrial experience.

Languages
The five languages used on the multilingual maps proved to be too many and required too much space. We therefore decided to use only English and one local language for each printed sheet and then to issue a separate printing for each language.

Grid and datum
We have shown both old and new longitude systems for Mars, explaining separately why we did so. Special latitude lines (e.g., tropics and arctic circles), can be shown for each planetary body according to its axis tilt. Also included are remarks about the current zero height levels and the definition of the 0° longitude.

Explanation
A detailed explanation of symbols has been included in which all landform symbols (areal and vectoral), height levels, and nomenclature terms are explained, including the "termless" crater names and other features without names. This explanatory part of the map uses geologic/geographic terms instead of, or in addition to, the IAU's Latin descriptive terminology. Where space permitted, we included photos for explanation.

Index
An index of names with coordinates and sizes, as in the IAU Gazetteer, was also added.

Scale
Also included is a scale bar, together with a written scale. It may be useful to draw the outline of the target audience's home country to the scale of the map.

Nomenclature, fonts
We have shown on the map some informally named features (such as the Face on Mars, the Happy Face Crater, Inca City, and Cobra Head), with short explanations. Using distinctive fonts consistently is important, since carefully selected typefaces provide yet another aid for the correct interpretation of a particular feature. A feature's characteristics are indicated by (a) its visual representation (shape, colour); (b) its name (generic element); and (c) the typeface, style, and size of its name. The terrestrial analogues – for example, water in cyan sans-serif italics, land in antiqua all caps, and mountains in condensed antiqua bold – can be transferred with appropriate changes.

THEMATIC MAPS

Explaining seasons and climate
Climate maps are an important part of school atlases. We have produced a climatic map of Mars that shows the average temperatures based on solar irradiation (solar climate zones), topographic location (heights, depths), cloud coverage (for mountains), and albedo (dark dunes vs. bright ice caps). On the main map, topographic colour-coding is also explained as atmospheric pressure change. For landing sites, where available, we have shown local yearly and diurnal temperature-change diagrams together with an explanation of the Ls system (the azimuthal position of the planet around its orbit, a measure of the seasons). Instead of precipitation data, which typically accompany such diagrams, we used pressure and wind data, available through one Martian year from the Viking observations. The periods of possible global dust storms are also shown. The same diagram also shows the yearly change in the planet's distance from the sun and the change in solar irradiation at particular latitudes.

Contour maps
Contour maps are essential for students' studies. In the case of the Earth, these maps show the hydrologic system and the borders of continents. Mountains are shown as thick black lines. For other planetary bodies, however, none of the above symbolism can be used: they have no hydrologic system, no continents, no sea level, no mountain chains. All planetary bodies have their own characteristic features, while craters are the most common landscape types. For Mars, we have included the north–south boundary, volcanoes as black spots, craters as circles, large valleys as lines, and crater-rim-mountains as grey areas. For the Moon, characteristic features are the maria, crater-rim-mountains, crater rays, and large craters; for Venus, continents, volcanoes, coronae, tesserae, and chasmata.

Morphologic sketch maps
During astronomy classes at Eötvös Loránd University, one of the tasks for the students is to draw simplified geomorphologic maps of various planetary bodies using topographic, geologic, and photomosaic maps. The task involves creating a coherent symbol system for their

Figure 7. A few of the symbols used by the students: (1) Volcanic cone; (2) Mountain; (3) Fossa; (4) Dorsa (Venus); (5) Arachnoid; (6) Valley (outflow and tectonic).

maps (see Figure 7). These students have a strong background in geography and geomorphology, but less experience in planetary science. Naturally, they use those symbols with which they are familiar. The result, even if not scientifically correct, has many useful visual and conceptual elements that can be used in drawing simple planetary maps.

In the overall appearance for Mars, the students used a white background for highlands and a striped background for lowlands. Since there are more features inside the highland areas than in the lowlands, the map is clearer this way. These are small but important details.

They also used the terminology and nomenclature with many errors, since they are not familiar with it. But this unfamiliarity shows exactly the "weak points" of it. For example, the students used the term "debris [or ejecta] mountain" for the Lunar circumbasin mountains (Apenninus), which exactly describes its nature. They used "Syrtis Major bulge" instead of Planum, "Mariner graben" instead of Valley, and so on.

Data section

The typical world atlas has a "Geographic Data" section in which geographic records are listed (e.g., the longest river). A similar data set was prepared using planetary records to list the largest, highest, and longest mountains, valleys, volcanoes, and depressions, among other features, in our solar system.

Paleomaps

Since maps of the Earth show our planet only in a "randomly" selected moment, an atlas can include paleomaps of the Earth for proper planetary comparison, together with estimations of the scales of now-disappeared features of our planet. Showing the Earth, the Moon, Mars, and other planets side by side could give a good comparative view of the ages of features and planetary surfaces. But this task was beyond our capabilities.

Extraterrestrial Geographic Names

From the *IAU Rules on Extraterrestrial Geographic Names*:

> Individual names chosen for each body should be expressed in the language of origin. Transliteration for various alphabets should be given, but there will be no translation from one language to another . . . Diacritical marks are a necessary part of a name and will be used . . . The number of names chosen for each body should be kept to a minimum, and their placement governed by the requirements of the scientific community. (USGS 2003a)

"Planetary nomenclature, like terrestrial nomenclature, is used to uniquely identify a feature on the surface of a planet or satellite so that the feature can be *easily located, described, and discussed*" (USGS 2003b). While this goal is achieved in scientific discussions, the present form of planetary nomenclature is less suitable for public education or popular science. The names use the Roman alphabet and Latin descriptive terms that are not familiar to a large segment of map readers. Most editors and popular writers, including English-speaking ones, do use local-language equivalents of these names, with or without the Latin form, in books, articles, and atlases. Since there is no guide for translation, they try their best, and in this way produce multiple translated, transcribed, or transliterated variants of the same feature name. Translation may seem unnecessary for the reader who understands an Indo-European language, since, even though the terms are not identical to those in their own language, they can deduce their meaning relatively easily: *Mons* = Mount, *Planitia* = (low) Plains. This is not the case for several other European and most non-European languages, in which Latin terms are meaningless.

In the case of maps for non-professionals or for a young audience, it might be better – somewhat in contrast to the efforts of the United Nations Group of Experts on Geographical Names (UNGEN) to agree on a *single* standardization of geographical names – to use *standardized national-language variants* of the Latin terminology, which would make it possible to answer the map readers' question, "What's there?"

SPECIFIC ELEMENT (PROPER NAME): NAMES AS LABELS

"The main function of geographical names is to serve as a label, and as such, its semantic meaning, even if evident, is of less consequence than its role as a designation or tag" (Kadmon 2000, 37).

History

For Lunar names in his 1645 chart, Langrenus used the names of contemporary kings and saints (and himself) and symbolic names for terrae; Hevelius used European geographic names to make his system easy to remember (1647); Riccioli used symbolic, geographic, and personal names of ancient and recent thinkers and scientists (1651). For Martian albedo names, P.A. Secchi used names of explorers (1850); R.A. Proctor used the names of past and contemporary astronomers (1864), while G. Schiaparelli used mythological and Biblical names (1877). The IAU adopted and extended the most "neutral" naming methods or themes, those of Riccioli and Schiaparelli. From 1959 on, Soviet scientists had the exclusive right to name newly observed features of the far side of the Moon, which resulted in a predominance of Soviet names. In 1970, the IAU Working Group on Lunar Nomenclature used a more international approach in adopting more than 500 names, most of them

Soviet and American, for the features of the far side. A few duplicate names still exist, including those of some catenae (RNII, GIRD, etc.) named after abbreviations of important Soviet rocket science organizations, which the head Soviet constructor of rocket engines, V.P. Glushko, insisted upon in compiling part of the *Atlas of the Far Side of the Moon* (K.B. Shingareva, personal communication, 20 May 2004). These names are still in use, but only in lunar maps published in Russia. We have shown both IAU and Russian names on our maps.

The nomenclature system of WHPSN is now truly international: of 5070 planetary names (excluding Lunar names), 12% are of Greek, 7% of Latin/Roman, 5% of British/English, 4% of Russian, 4% of American, 3.5% of French, and 2.5% of Norse origin. The remaining 62% is taken from 280 past and present nations, cultures, and countries whose numbers are constantly growing (USGS 2006). These nations keep count of their "presence" on solar-system bodies as part of their national pride; it can even be the single subject of books (e.g., Sárneczky 2005).

Meaning

In planetary science, the naming of features tends to be artificial, or based on bureaucratic processes. Except for operational, informal, and traditional names, there is no real connection between the proper name and the feature. In some cases there is an indirect connection: they may be named after scientists who studied that particular planetary body or names related to the name of the planetary body. Some association to the object may also exist, as in the case of Io (its volcanic centres are named after gods of fire), Mimas (discovered by W. Herschel in *England*; its place names are taken from the *British* legend of King Arthur), or Enceladus (which has such a strange and mysterious surface that it was given the Arabian Nights as a name bank; Owen 2002). Sometimes there is a connection with the names of neighbouring features; in one case, craters named after Hungarian scientists are grouped as one cluster on the far side of the Moon. On Titan, radar-bright features in radar-dark areas are named for terrestrial islands, indicating a theory according to which these places are indeed island in a fluid(-like) material.

The *meaning* of planetary features may be transparent and readily understandable or opaque. Today, both elements of extraterrestrial names are usually opaque to all readers who have not learned Latin or who are unfamiliar with the mythology or legends of various cultures, although this was not the case at the time when the Latin/mythological naming tradition originated. For some traditional names both elements are translated, but the name remains opaque or has a "*false*" (descriptive) *generic* that does not describe the feature, as well as a false specific considering its meaning. An example is the translation of Mare Imbrium as Sea of Rains. Here the geologic term would be better understood (Imbrium Basin), but this has a different meaning in geology (the original crater). While the meaning itself is of secondary or little importance in scientific publications, the meaning or its historic connections can be more important, or just interesting, to the general public. This fact argues *for* the restoration of the original meaning in the local language. The labelling function, however, argues *against* any attempt at translation, or even transcription or transliteration, of the names. A traditional exception is when the specific element contains compass points, which are usually translated. A current example is the problem of translating the geological name "South Pole – Aitken Basin," *not* an official IAU name.

Informal names

Astronaut- or mission geologist–named features of the Moon and "named stones" on Mars are somewhat outside the nomenclature, since they follow neither the IAU rules of naming features nor the terms used for lunar features. But, in fact, this is the case when a feature gets its name by a natural naming process; therefore, the name is related to the characteristics of the named object and/or to those who named it. The rule here is usually that the names be easy to remember, and not be derogatory (Morton 2002). Such informal (operational) names are given by the scientists or astronauts working on the particular landing mission, who until now, have mostly been Russians and Americans. The generics are usually in English (Mountain, Massif), while the specific elements of features named on recent missions are, in many cases, taken from American culture: Snoopy, Scooby Doo, Zaphod, Photometry Flats, Family Mountain, North Massif. In some cases the names are officially assigned, including, for example, Independence on Mars. Here, the same translating rules apply as for terrestrial maps, which leaves open the question of whether to translate one or both elements of the name. In practice, the generic is usually translated, the specific only rarely, and sometimes both are kept in their original form, like *Mont Blanc* in most languages.

Widely used informal names on the Moon include Cap Banat, Great Wall, and Cobra Head; on Mars there are names such as Inca City, Happy Face Crater, and Giant's Footprints. Since most lunar observers do use these unofficial names, a map should also display them. They should be given in the original or the target language, not in an artificially Latinized form, since in this case the meaning is more important than the labelling function. It might also be interesting for the map user to see some of the historic names (Hourglass Sea, Nix Olympica) that can still be found in science history–related texts.

DESCRIPTIVE ELEMENTS (GENERIC ELEMENT, GENERIC TERM, DESCRIPTOR TERM)

The system of most Latin descriptive elements was developed in Sydney, Australia, by IAU and USGS astrogeologists for Mars in 1973. Usually the IAU descriptive elements are meaningfully related, as far as our current knowledge makes possible. The meaning refers to the topographic nature of the feature and does not reflect its geology or formation. As its term used by IAU implies: descriptive elements only the shape of the feature. This is a good method when we have no proven theories concerning the real nature of the feature. A classic example is the descriptive word "crater," which is used for both impact and volcanic structures that, in some cases, indeed have very similar morphology. In planetary nomenclature, crater names without a descriptor term refer to impact craters. If a crater is of volcanic origin, the term Patera is used. So there is some references to the geology of the feature even in descriptor terms. There are also some intentionally (traditionally) false descriptor terms for some lunar features: Mare, Sinus, Lacus, Palus (a system originating from Langrenus). The translation of both elements in this instance is traditional; however, this also makes lunar nomenclature false in the target language. Such names on Mars once existed, but these features have been renamed.

In some cases (a) the generic Latin term has a terrestrial parallel term (Mons-Mount); or (b) it can be kept in the original form, but transcribed/transliterated to the target language (Tessera-Tesszera). In other cases, however, the descriptor term is somewhat misleading in terms of geology, which is not surprising, since these terms *describe*, not interpret, features. For example, a *farrum* (pl. *farra*) is defined as a pancake-like structure, or a row of such structures, while structures of the same morphology are named *tholus* (pl. *tholi*) on Io. Similarly, the terms *tholi* and *paterae* usually refer to shallow, volcanic calderas with or without cones, respectively, while calderas on high volcanoes are not named. The term *mons* (pl. *montes*) indicates crater ejecta materials or impact basin rims on the Moon and Mars, while smaller craters' rims are not named. The same terms on Venus and Io, however, denote features of different origin, having no relation to impact processes. *Basins* are large impact craters, but where is the threshold between basins and craters? Impact basins on Mars do not have their own descriptor term. The same term is used for them as for plains (*planitiae*), although their basin structure may be more characteristic. And *basin* is still not an interpretative term. *Plana* (highlands) are high(er) only on a global scale; on a regional scale, they are "just" plains. The lava-filled basins are traditionally called *mare*, but only on the Moon. The English word *basin* is used in geology to describe the original structure. *Coronae* (sing. *corona*) are "ovoid-shaped features," but these (probably) are of a different nature on Venus and on Miranda. Venusian coronae have many types – arachnoid, nova, corona – which have names used in geology. The latest descriptor term in planetary nomenclature is *astrum*, proposed by A.T. Basilevsky, for radial patterned features of Venus. Some of them have previously been named with the term *corona* or *mons*, but such designations have caused problems for geologists who are mapping these areas (Burba and others 2001). Geologic terminology of the various ejecta craters of Mars required standardization because of the inconsistent use of the terms (Barlow and others 2000).

An unusual part of planetary nomenclature concerns the Moon, where, in contrast with its former nomenclature and the current Martian nomenclature, there are no regional names assigned for the highland regions; there are no separate *terrae* on the Moon, although there used to be on the map of Langrenus. Thus, the highest hierarchical level is missing on this part of the Moon, which makes up most of the far side.

Large-scale features are not well defined on other planets either. "The boundaries of many large features (such as terrae, regiones, planitiae, and plana) are not topographically or geomorphically distinct; the coordinates of these features are identified from an arbitrarily chosen center point. Boundaries (and thus coordinates) may be determined more accurately from geochemical and geophysical data obtained by future missions" (USGS 2003c). This is also true for Earth, but with a much smaller "uncertainty zone." This might help in defining Lunar regionally named features as well.[1]

For a translation method here, I recommend keeping the labelling function (thereby avoiding more chaos) of the specific element, which, in terms of meaning, usually has little reference to the feature itself (no Blue Mountain on Mars – yet), while the generic element (term) should be made transparent, since it does make reference to the characteristics of the feature.

We may try to keep as many names as possible in Latin forms, while also keeping the widely used traditionally translated or exonym forms. It is also possible, in personal communication, to avoid the use of generics where possible, referring to landforms such as "Hellas" or "Ascraeus" by adding the geologic term of the feature (basin, volcano).

ENDONYMS, EXONYMS

Endonyms are local names for local features. Extraterrestrial names cannot be endonyms, except perhaps for the names given "locally" by astronauts. But they can be based on and named after terrestrial, geographical features (mythological characters) that, in some countries, have an endonym form.

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Exonyms are names used in a specific language for a geographical feature outside the area where the language has official status, such as "Vienna" or "Bécs" for the Austrian city of Wien. These should not be translated to the target language's existing exonym form because they will then lose their labelling function.

Greek personal names, mythological characters, and place names are Latinized in planetary nomenclature. On Jupiter's moon Io, however, instead of a neutral Latin form, the IAU used the English exonym forms of many terrestrial geographic names, such as Danube and Ionian (sea), to name plateaus and mountains. These names have several local endonyms because the terrestrial features cover several countries. The IAU's choice of contemporary English exonyms instead of "neutral" Latin forms may be questionable. This does, however, make it more difficult to decide which version to use – the English exonym or the local endonym of the same feature. A label should use the official English form, but as a geographic name in many languages, our examples have endonyms and other forms of exonym, such as, in the case of Hungarian, Duna and Jón. If the terrestrial "donor" feature is located in the area of the target language, the usual, traditional preference is that form ("the Carpathians" instead of Carpatus Montes). It is an open question whether to extend the rule of using endonyms or exonyms for other toponyms that have no such tradition, such as using Danube Planum on Io. Using exonyms for geographic- and mythology-related planetary names is the current practice in Russian publications (Shingareva and Krasnopevtseva 2005).

Most extraterrestrial names are neither endonyms nor exonyms; they are standardized, artificial international names. However, some names have become exonyms for most languages over the last centuries. Such are the maria of the Moon and the most prominent features of Mars, whose names are in fact historic or mythological exonyms. These can be kept in their traditional form where all elements are translated, as on the Moon, or replaced with the standard non-translating method, whereby, on the Moon, Mare Imbrium becomes Imbrium Plains, as if it were Imbrium Planitia, which sounds alien to most astronomers but best fits a standardized nomenclature and still differs from the existing geologic name (Imbrium Basin).

CLASSICAL NAMES: A POETIC ARGUMENT

As spacecrafts pass by planetary bodies, terrestrial, but sometimes heavenly, myths and legends move to those celestial bodies as place names, thus getting a new life. This "side effect" of planetary discoveries is in itself an important cultural phenomenon raising interest in this subject.[2]

The so-called classical albedo features (Mars, Mercury), which were used, although differently, well before the establishment of the IAU and are still used extensively by amateur astronomers, bring up other questions. Should we use the local (exonym?) versions of these mythological names, which in many cases are transcribed or transliterated? Or had we better drop the traditional mythological form, reconsider these names again as labels, and keep the Latinized form? In this way many names would become opaque, whereas if we apply the necessary (slight) changes, the original "poetic" meaning[3] that had an important role in popularizing Mars in the nineteenth century can be restored. Schiaparelli established the rule of giving mythological names for landforms, which became very popular and, perhaps more importantly, were easier to remember for the educated people of that century. He transferred the Greek mythological map of the Mediterranean to Mars using some associative thinking. At that time it was also a common practice to show names on terrestrial maps in Latin form (e.g., Mare Germanicum) so that his Latin nomenclature fitted perfectly into the terrestrial nomenclature system and was transparent to map readers. Our goal is that, at least partly, this "sense" of names be re-established in their modern form; but, of course, in international scientific articles only the original IAU nomenclature should be used.

TRANSFORMATION WITHOUT TRANSLATION

There are two options for transformation without translation: (1) *Transcription*: phonetic transformation of a name (for non-roman alphabets); usually the original form cannot be restored from the transcribed one. (2) *Transliteration*: transformation letter by letter, where the original form can be restored from the transcribed one. While international *single Romanization methods* (Russian, Chinese Pinyin) make international trading, international scientific discussions, and map-making much easier (or make it possible), names transliterated using these rules (a) do not fit the various languages' own systems, (b) look alien to many because they contain letters that are not used in some languages, and (c) are usually are difficult or impossible to pronounce for those not familiar with the Romanization principles. This probably includes most people, not because they cannot pronounce the relevant sounds but because they do not know how to read or interpret particular letters.

Most languages have their own transliteration or transcription rules from non-roman alphabets that do fit the language's character. In Hungary, some terrestrial maps use international Romanization while others use the local method defined by the Hungarian Academy of Sciences, so the question remains open even for terrestrial maps.

ORTHOGRAPHY

All extraterrestrial geographic names follow the Latin (and English) tradition. They are composite names with the first letter capitalized and the elements written separately, except for craters and ephemeral features, which have no generic. However, geographic names in some languages have different rules. Hungarian, for example, uses a hyphen between the two elements, and the generic term is written without an initial capital letter.

BILINGUAL OR BISCRIPTURAL MAPS: EXTRATERRESTRIAL ALLONYMS

Allonyms are alternative names – several toponyms for the same feature. These can be shown in a multi- or bilingual gazetteer and on multilingual/multiscriptural maps. For maps, space is a limiting factor, so only the most prominent features should be written in two languages/scripts (the target language and the international form). Craters, fortunately, have no generic element. In the case of craters named after words or names originally written in Cyrillic letters, on our test map we always displayed the original Cyrillic form as well. This can be done only if most of the target audience at the date of publication can read that alphabet.[4] For nations using a non-roman alphabet, maps can display both the local form and the official Latin form.

CHANGES IN THE NOMENCLATURE

As place names on Earth change with history, place names also change on other planets, because of standardization, historical events, and scientific considerations. Planetary nomenclature was cleared and standardized by the IAU for the Moon in 1935 and for Mars in 1958 and 1973 (Greeley and Batson 1990). During the discovery (mapping) of a celestial body, new names with naming rules and descriptor terms, if needed, are created. If a more detailed image shows that a feature has been misinterpreted, the generic element of its name is changed, as in the examples of Cerberus Rupes (changed to Cerberus Fossae) and Cleopatra Patera (changed to Cleopatra [crater]). Other features' names are dropped because they turn out to be only part of another feature or to be non-existent during revision of the images, as in the cases of Sovietsky Mountain, Moon, and Seshat Mons, Venus. Additional minor revisions may include changing the descriptor term from plural to singular or vice versa to fit the real situation, as well as corrections in spelling (Burba and others 2001).

CASE STUDY: HUNGARY

In Hungary, no rules for how to write planetary feature names have been established. For major planetary bodies, the previous chaos was clarified in the 1970s by rules stating that names of planets should be written according to their pronunciation (e.g., Vénusz instead of the formerly used Venus). However, no rules were defined for names of moons, asteroids, or planetary features, and only some suggestions exist (Hargitai and Kereszturi 2002). Now names of minor planets are written in the official IAU form (i.e., the Latinized form), perhaps because the use of language has changed. Now the original Latin name seems more appropriate for moons and asteroids, at least for planetary scientists, who are accustomed to these forms. But they are not necessarily more appropriate for young students or for the general public. In many publications in Hungary (especially those translated from English), the names of Jovian moons are translated using the local traditional name of the mythological character in question (e.g., Europa = Europé; Ganymede = Ganümédész).

We are aware that not only the names but also the methods of transforming/translating geographical names change with time, or there may be parallel schools that use different methods, as is the case in the cartographic community in Hungary.

FUTURE NOMENCLATURE

Several scientific articles discuss unnamed features that are identified by their coordinates. For the yet unvisited worlds, the presently known albedo features are, in most cases, not named, as is true for Pluto and Charon. In the future many new features will be named in the Saturn system, new terms will be used, and new planetary bodies will get their own nomenclature systems. After such discoveries, especially, new names can come out quickly and easily, as was the case when discovering the far side of the Moon, but may not conform to IAU rules. One of the latest examples is Circus Maximus on Titan, which, at the time of writing, is not yet an official name. But as the first features identified from radar observations on Venus remained on the maps (Alpha, Beta), it is possible that Circus Maximus will have the same future. With new landings and rover missions, naturally created names will also appear in great numbers. There is an urgent need for a general guide on how to translate these names to other languages in a controlled or standardized way.

Conclusions

In the case of publishing planetary maps for a non-expert readership, we propose to use common Latinized or internationally Romanized specifics (without translation) and separate (translated or transcribed/transliterated) generics for different languages, as is done for many undersea features on terrestrial maps. The specific elements should never be translated, except for those features that have a traditionally translated variant. It is also recommended that maps show, as much as the available space makes possible, a bilingual (international and local) nomenclature on planetary maps, especially in the case of names with translated specific elements.

The visual appearance, symbol system, and contents of planetary maps should be closer to terrestrial maps, as this makes them easier to interpret correctly. Comments and height data appearing on the map can also help to improve its comprehensibility. Thus the reader can form a more realistic mental map of the particular planetary body.

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Notes

1. It should be noted that undersea feature names resulting from the same internationally standardized, artificial naming conventions are always shown on maps in the target language, both their generic and specific elements.
2. An Internet search on numerous mythological names usually yields results in planetary science, not mythology.
3. For a detailed explanation, see Macdonald (1971).
4. Today this is changing very rapidly in the case of Hungary.

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