RASTER VENUS AND LUNAR MAPS AS A SOURCE FOR OBTAINING VECTOR TOPOGRAPHIC DATA

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Abstract
The new hypsometric maps of Venus and the Moon should improve and accelerate studying the surfaces of these planets and relief-forming processes. Additionally, these maps should be useful for students and scientists. The hypsometric map of Venus is produced in Lambert equal-area azimuth projection. Its height contours are obtained using the Magellan altitude data. To create Lunar Subpolar relief map the authors obtained heights from the A. Cook et.al. raster image of South Lunar Subpolar region (latitudes from -60° to -90°) being constructed in stereographic projection. [A.C. Cook, T.R. Watters, M.S. Robinson et.al. (2000) JGR, Vol.105, E5, 12023-12033]. Morphometric investigations of Venus and Lunar South Pole region surface have been fulfilled using our databases. The height profiles of some lunar craters being situated here and detailed profiles of the whole this area created by us describe the features of this region surface with the high resolution up to 100 meters.

1. THE HYPSOMETRIC MAP OF VENUS

1.1 Introduction

Due to the modern space technology it has become possible to study the planets of the Solar System in ever greater details. In particular it is true for Venus, whose surface is hidden by a thick atmosphere leading to the fact, that its surface relief can be only observed using radar techniques. With the data received from the spacecraft Pioneer Venus (1980), Venera-15 and -16 (1984) and Magellan (1994), hypsometric maps of this planet are created and improved concerning its accuracy.

The new hypsometric map of Venus hemispheres are created by E. Lazarev (the editor is doc. Zh.F. Rodionova) at Shternberg State Astronomical Institute and Geographical Faculty of Lomonosov Moscow State University. Additionally detailed morphometric investigations of this planet are accomplished too. Now, the corresponding researches are continued at Moscow State University for Geodesy and Cartography.

Actually, the compiling of Venus hemispheres hypsometric map and some cartometric investigations using this map are part of author's PhD thesis. Using the Clementine data and some other types of data, the author still produced the map of the Moon. It is planned, that these maps should complete the series of hypsometric maps of terrestrial planets and their moons. Now, only the hypsometric map of Mars at a scale of 1:26M is still published. The hypsometric map of Venus hemispheres is prepared for publishing. The map of the Moon is compiled. We hope to obtain the full hypsometric map of Mercury as soon as the information from space-researcher *Messenger* would be available.

The comparison of the Venus hypsometric map with the Venus map in the «Atlas of the Terrestrial planets and their moons» created in MIIGAiK [1] shows that the new map is improved and is more precise thanks to obtaining up-to-date remote sensing data from spacecraft at the orbit of Venus (*Magellan* (1994)). Really, it includes the more exact and informative hypsometric information of Venus. In contrast to the most of small-scale general maps created by the last space researches and compiled in the cylindrical projections (mostly in Mercator projection) [2], our map is compiled in

Lambert equal area projection. The original level scale, named contours and names of relief forms in Latin and Russian belong to advantages of this map.

1.2 Techniques of Venus Hypsometric map compiling

The hypsometric map of Venus is created based on *Magellan* database consisted of three columns x (latitude), y (longitude) and z (radius). The heights at Venus are referenced to a sphere of radius 6051.0 km corresponding to the mean radius of the planet.

Contours are constructed using heights of 64 800 points for 1-degree trapeziums obtained from the database of 33 million points. For this aim, a special program is written in the C++ program language. Automatic extracting of points with this accuracy is completed using this program and leads to the database of 64 800 points. Coordinates and high information are attributes of each point. The enlarged points' quantity is considered in the areas of extreme values of heights (Maxwell Montes, Maat Mons, Atalanta Planitia) with the aim of improving precision.

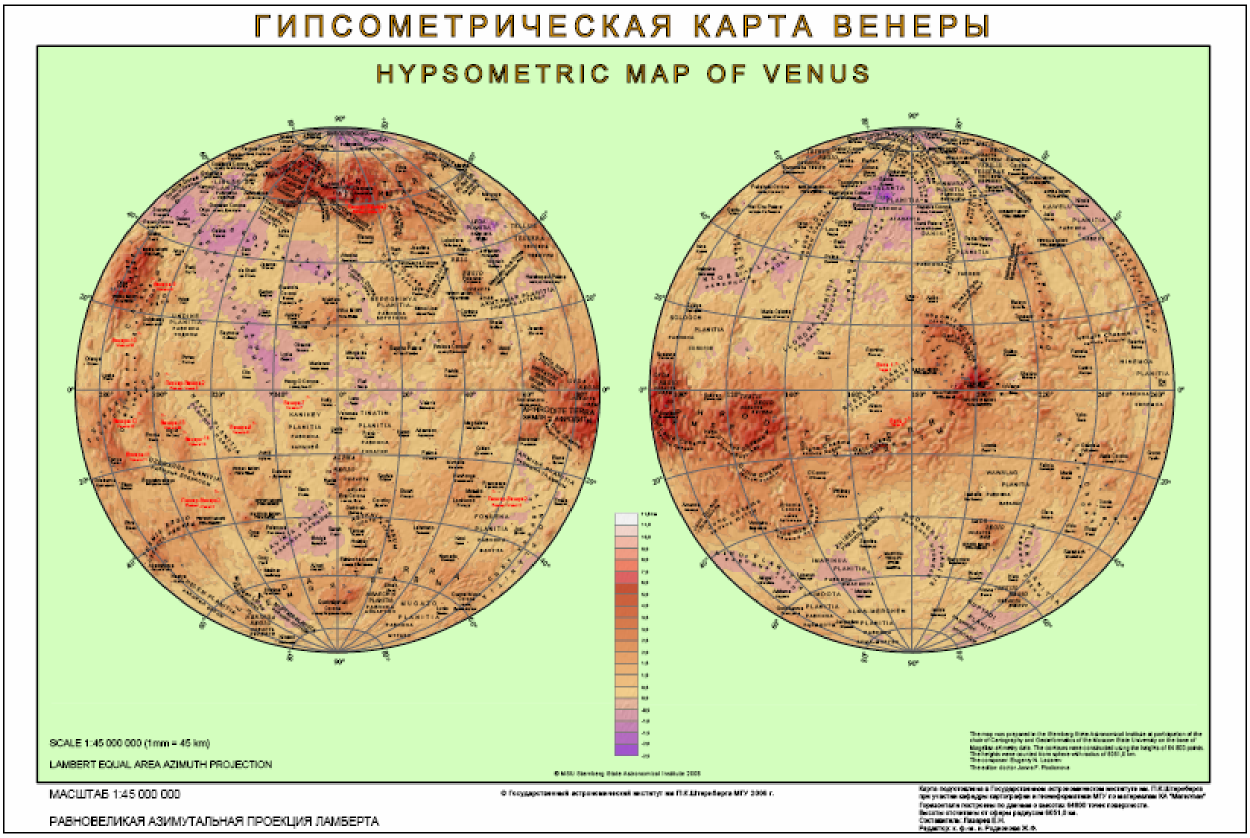


Fig.1 Hypsometric map of Venus (the original scale is the 1:45M)

Further, the entire volume of points is divided into two hemispheres with the central meridians are 0° and 180°. And after that contours are constructed for each hemisphere. The hypsometric map is compiled in Lambert equal area azimuth projection at a scale of 1:45M and is shown in Fig. 1.

As well as the processing of contours, the work at all subsequent stages of map compilation are made with the help of ESRI software products ArcINFO/ArcGIS. Contours are drawn using points being situated away from each to other at 1°.

The contour line interval of this map is 0,5 km and corresponds [–2, 4 km]. But it is 1 km for levels higher than 4 km (Fig.2). Such intervals are usual for Venus hypsometric maps. The multicolored and lightened scale is chosen because such scales are advisable for the ridged mountain areas [7].

In the following step, the contours generalization should be accomplished. The main requirement is to remain contour polygons with the areas, which are greater then 10 000 sq. km at the Venus surface. They correspond to areas approximately greater than 5 sq. km at the map. Contours in the areas of extreme values of heights (Maxwell Montes, Maat Mons, Teya Mons, Atalanta Planitia, Leda Planitia, Polar areas etc.) are showed with exaggeration.

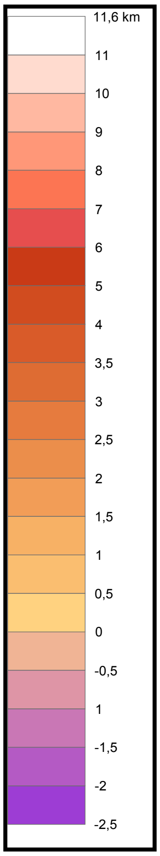


Fig.2 The height scale of the map of Venus

Parallels and meridians of the Venus coordinate network are made every 20° of latitude and longitude. The longitudes of Venus are measured from meridian of zero in the eastern direction from 0 to 360°. The Venusian zero meridian intersects crater Ariadne in the North hemisphere.

Names of relief features are plotted at two languages (Latin and Russian). Using types are represented in Table 1.

Table 1.

type	relief features
ISHTAR TERRA ЗЕМЛЯ ИШТАР	terrae
LAKHSMI PLANUM *ПЛАТО ЛАКШМИ*	plana
ALPHA REGIO *ОБЛАСТЬ АЛЬФА*	regiones
SNEGUROCHKA PLANITIA РАВНИНА СНЕГУРОЧКИ	planitiae

FORTUNA TESSERA ТЕССЕРА ФОРТУНЫ	tesserae
• MAAT MONS ГОРА МААТ • MANUEA THOLUS КУПОЛ МАНУЭА	montes, tholus
Vesta Rupes уступ Весты	rūpes
type	**relief features**
Vedma Dorsa гряды Ведьмы Diana Chasma каньон Дианы Bellona Fossae борозды Беллоны Morrigan Linea линия Морриган	dorsa, chasmata, fossae, linea
• Eve Corona венец Евы • Sappho Patera патера Сапфо • Tsvetayeva Цветаева	coronae, paterae, craters
Венера-13 Venera-13	places of spacecrafts landings
• 11,6 • -2,5	marks of heights

Places of spacecrafts landings and height extrema corresponded to some famous relief features are placed on the map as well.

The other side of Venus (fig. 3) map includes descriptions of planet geologic structure, images of relief features and some mythological heroines [8]. A part of this description is represented in Table 2. Graphs of morphometric investigations and photos of surface regions are at the other side of the map too.

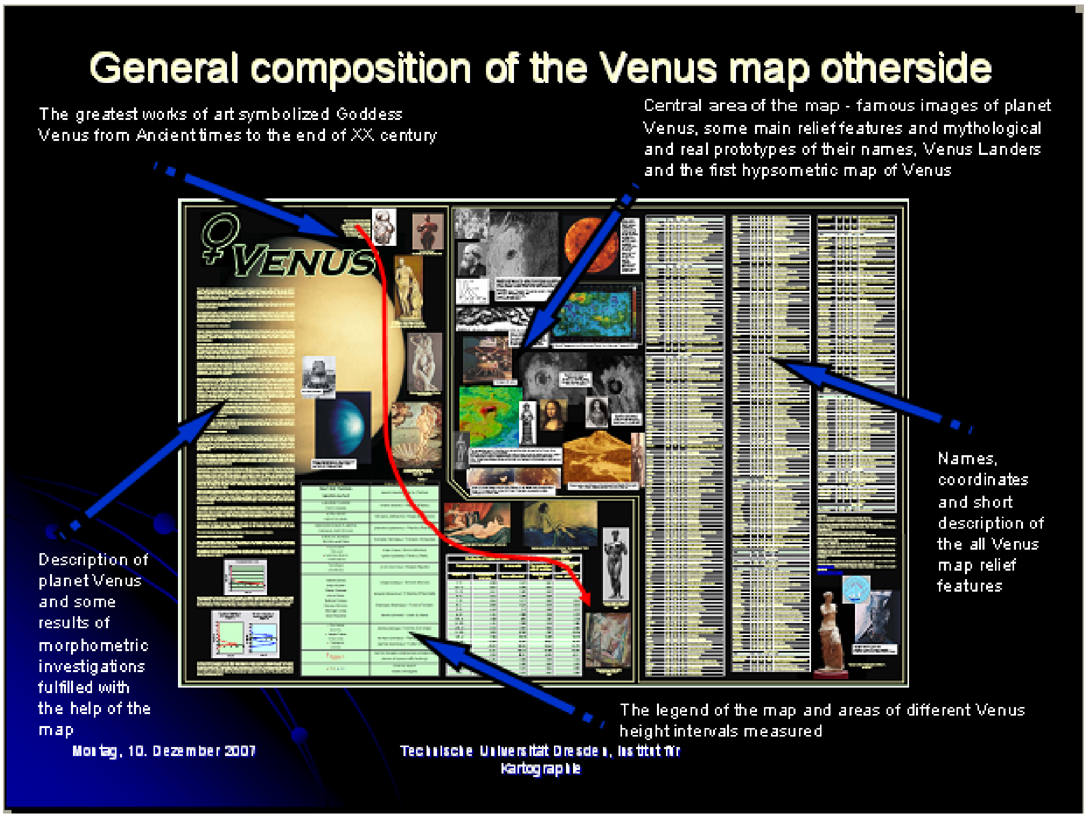


Fig.3 The otherside of the Venus map

Table 2.

Fossa, fossae				
Name	Lat	Long	Diam	Origin
Bellona Fossae	38.0	222.1	855.0	Roman war goddess, wife of Mars.
Linea, lineae				
Name	Lat	Long	Diam	Origin
Morrigan Linea	-54.5	311.0	3200.0	Celtic war goddess.
Mons, montes				
Name	Lat	Long	Diam	Origin
Akna Montes	68.9	318.2	830.0	Mayan goddess of birth.
Atira Mons	52.2	267.6	152.0	Pawnee (N. America) wife of Great Spirit Tirawa.
Danu Montes	58.5	334.0	808.0	Celtic mother of gods.
Freyja Montes	74.1	333.8	579.0	Norse, mother of Odin.
Gula Mons	21.9	359.1	276.0	Babylonian earth mother, creative force.
Hathor Mons	-38.7	324.7	333.0	Egyptian sky goddess.

1.3 Cartometric investigations

Created map should be used for some morphometric investigations of the Venus surface. Table 3 shows the areas of different height levels.

Table 3.

Distribution of heights on Venus		
Height, km	**Area, million km^2**	**Percentage of total area**
> 11	10	0,00
10 - 11	30	0,01
9 - 10	50	0,01
8 - 9	80	0,02
7 - 8	110	0,02
6 - 7	210	0,05
5 - 6	1190	0,26
4 - 5	5950	1,31
3 - 4	10800	2.37
2 - 3	27590	6.05
1 - 2	104990	23,05
0 - 1	257230	56,46
-1 - 0	47030	10.32
-2 - -1	360	0,08
< -2	10	0,00

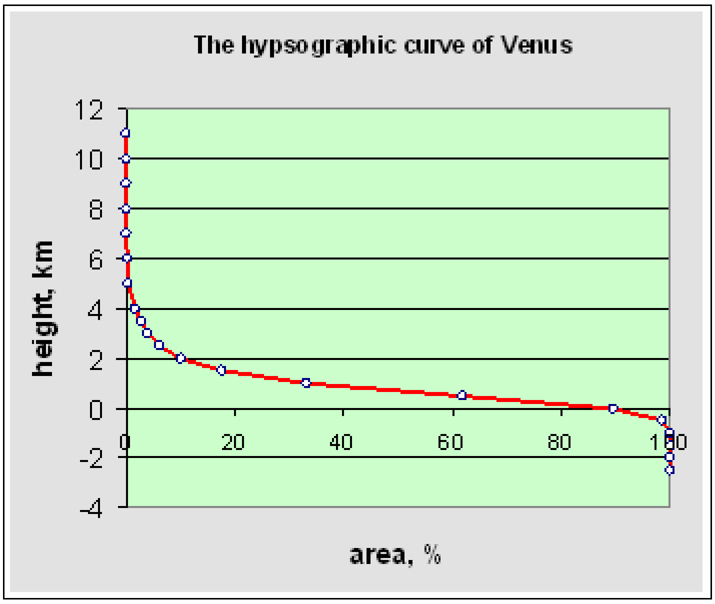


Fig.4 The hypsographic curve of Venus

The hypsographic curve (Fig.4) shows the maximal height of 11600 m (Maxwell Montes) and the minimal height of -2500 (Atalanta Planitia). The comparison of this curve with that for Earth mirrors the fact, that Venus curve have a unimodal spreading of heights with a peak between 0 and 1 km while the Earth has a bimodal allocation of heights with two peaks (21% between 0 and 1 km, 23% between -4 and -5 km). The range of heights on Venus is 14 km in contrast to 20 km on Earth.

Surface height histograms for both Earth and Venus (Fig.4) are shown in curves of heights frequency, where the areas are shown as percentages of the total: 455.6 Mkm^2 for Venus and 511.2 Mkm^2 for Earth. Besides the main peak, a small peak can be seen between 4 and 5 km, representing the highland plains for Venus. Within Ishtar Terra these are Lakshmi Planum and the region to the east of Maxwell Montes, as well as the western part of Aphrodite Terra. The mountainous regions make up 10,1% of the surface, hilly plains 79,5%, and lowlands 10,4%.

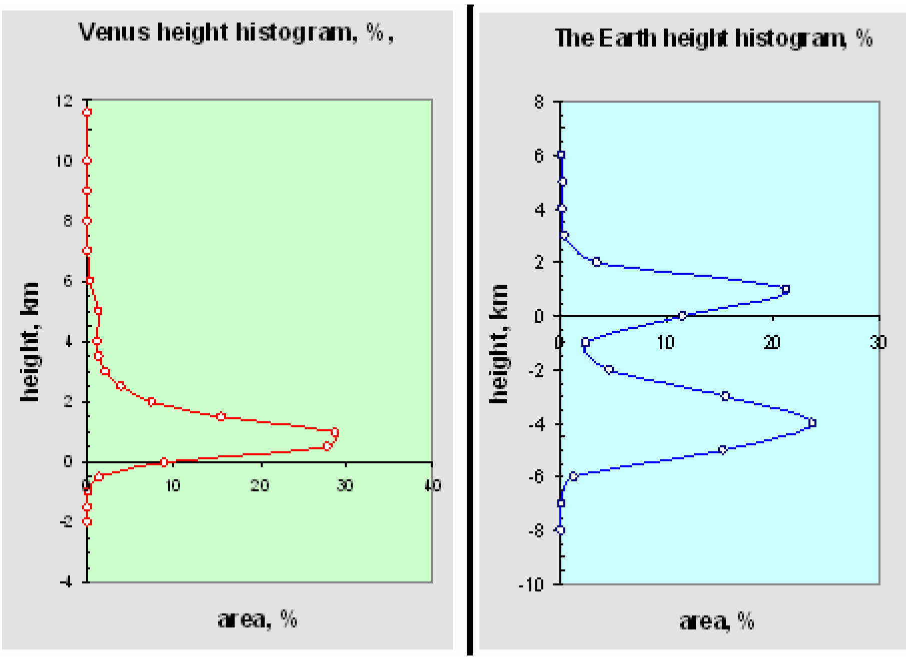


Fig.5 The Surface height histograms of Venus and the Earth

The different height profiles are constructed using the created map too. There are both the global profiles all along meridians and the local profiles such as the height profile of the Maxwell Montes. This profile shows a vertical ruggedness of the highest hills of Venus, the prominent crater Cleopatra at the east slope of mountains and allows seeing one more top to the west from the maximal mark.

2. THE HYPSOMETRIC MAP OF THE MOON

2.1 Introduction

During next years it is planned renewing spacecraft exploration of the Moon. For example, in August 2007 Japan Aerospace Exploration Agency plans launching the Moon explorer SELENE with 14 science instruments on board including the high-resolution stereo imager Terrain Camera (TC). The height resolution of Digital Terrain Model (DTM) produced from the TC stereo data is expected to be 20m or better. And it will be the first terrain model covers the entire surface of the Moon with 10m spatial resolution, and used for the various fields of lunar sciences. It is planned to publish the global TC Ortho map to be produced by mosaic of TC data [9]. At the same time NASA's Robotic Lunar Exploration Program (RLEP) will execute a series of robotic missions that will pave the way for eventual permanent human presence on the Moon. The Lunar Reconnaissance Orbiter (LRO) is first in this series of RLEP missions, and plans to launch in October of 2008 for at least one year of operation [10]. LRO will employ six individual instruments to produce accurate maps and high resolution images of future landing sites, to assess potential lunar resources, and to characterize the radiation environment.

The most interesting lunar region for this research is the Lunar South Pole area because it is suggested there are deep flaws with water ice never being under sunlight and being situated into the shaded craters of this territory. Owing to processing of spacecraft Clementine stereoimages [11] we got the database of the Lunar South Pole region including latitudes, longitudes and heights of 4,5 million points for this area. The morphometric investigations of the Lunar South Pole region surface have been fulfilled using our database. The detailed profiles of this area created by us describe the features of this region surface with the high resolution up to 100 meters.

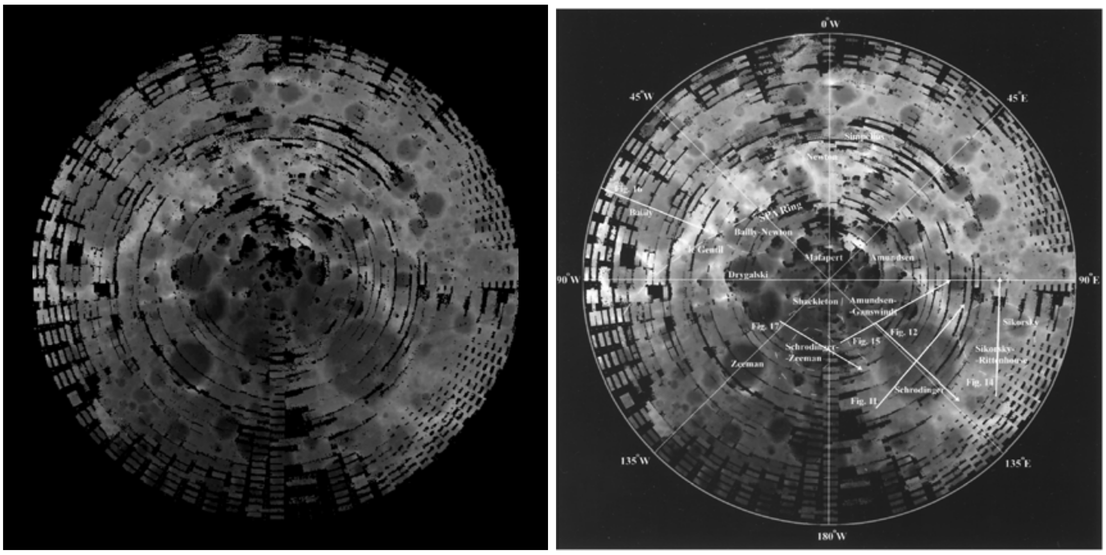
A

Fig.6 Raster image of South Lunar Subpolar region (latitudes from -60° to -90°) and the same image with coordinate net [11].

2.2 Techniques of investigations

Clementine data is the only available one for the whole lunar surface today. In 2000 A. Cook et.al. had compiled Digital Elevation Model (DEM) on the base of Clementine 1 km/pixel stereoimages with the relative height resolution of about 100 m [11]. The absolute errors of heights at this model make up ± 0,7 km for the whole Lunar South Subpolar region, but errors in areas being to the south from parallel 79° can make up ± 1 km.

The heights of DEM having compiled by A. Cook et.al. [11] were counted from the mean radius of the Moon of 1737,4 km. According to our investigations fulfilled on the base of different height level areas measuring at the Hypsometric map of the Moon having been created using heights of 64 800 one degree trapeziums, the mean radius of the Moon is equal to 1737,577 km [12].

To create Lunar Subpolar relief map the authors obtained heights from the A. Cook et.al. raster image of South Lunar Subpolar region (latitudes from -60° to -90°) [11] being constructed in stereographic projection. To reference this raster image the same one with coordinate net was used (fig.6).

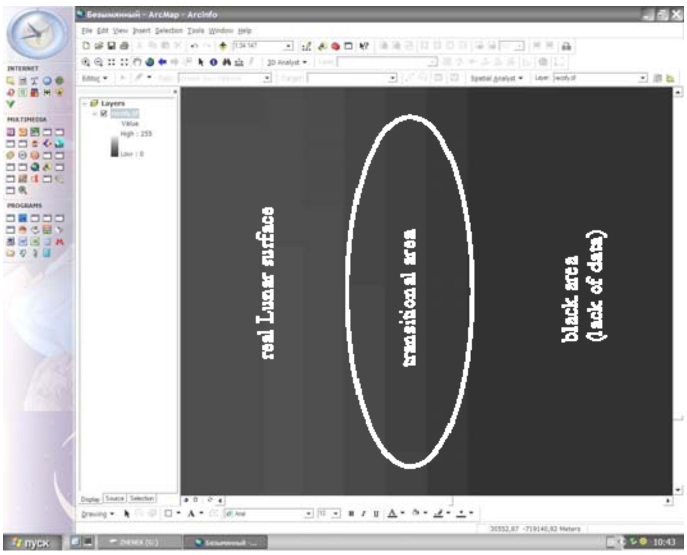


Fig.7 Lunar surface being at largest scale in the window of program ArcGIS

After the raster was referenced and exported to GRID-format, the next step was the obtaining database with the help of ArcView v3.3 script grid2xyz.avx [13] so that each database line was corresponded to each image pixel. The attributes of each line were coordinates of pixel center and its brightness. The size of database obtained was more than 250 megabytes or more than 6 millions points.

After editing database that is the removing of wrong lines, where brightness was equal 0 (black areas with data lacking) and 255 (the white raster frame) the total amount of points became equal 4,5 millions. During this stage of processing information some problems being corresponded to the origin raster appeared. There are the transitional zones situated on the border between real lunar surface and black areas with data lacked. The thickness of this zone is about 3 – 4 pixel (fig.7). At this figure one can see that the real lunar surface (on the right) and black area (on the left) are divided by area consisting of pixels becoming brighter gradually. The values of pixel brightness GIS-program gives the point attributes are not corresponded to real values of the lunar surface. To remove these points from the database, the buffer zones were created round of every black area.

After that the database had been made and edited we created the shape-file to comlile the Digital Realief Model of Lunar South Pole region. For that point attributes of the database had been visualized and converted to the shape-file in stereographic projection with the help of ArcGIS v9.0 (fig.8).

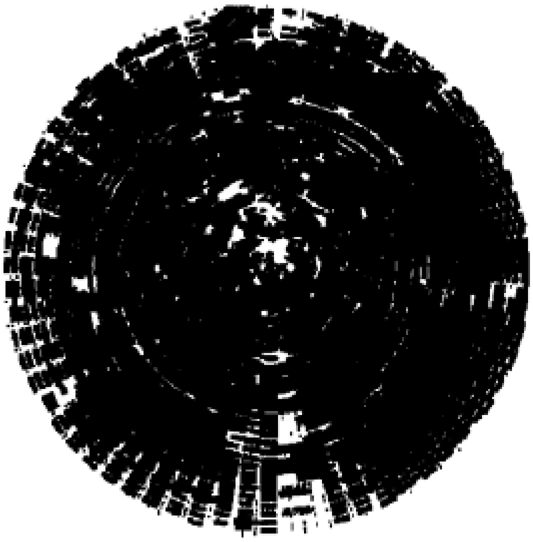


Fig.8 The point shape-file of the Lunar South Subpolar region in stereographic projection

Then the values of brightness were counted into values of height using the next equation:
$\boldsymbol{h = 75 \cdot I - 8700}$, $\boldsymbol{h}$ – point height, $\boldsymbol{I}$ – brightness.

The shape-file we had got was opened in the new ArcGIS frame in geographical coordinate system. As we were in the need of projected (spherical) coordinates in degrees to add them into our database instead of geographical coordinates in meters, the latter was counted into spherical ones.

The next stages being necessary to compile the Lunar Subpolar relief map are the joining Clementine laser altimeter data to data obtained and counting them correlation, constructing of contours, adding the shaded relief and the final map compiling. In this article we described map creation of the Lunar South Pole region, but as well it is proposed to create the relief map of the Lunar North Pole region. It is being fulfilled today and the final result of our work will be the Lunar Subpolar relief map with contours. But even now we can fulfill the different morphometric investigations of this interesting region of the Moon.

2.3 Using the data obtained. Morphometric investigations

Based on database obtained height profiles of the Lunar South Pole region along 0°, 90°, 180° and –90° meridians were created. The height profiles of some lunar craters including crater Schrödinger (latitude -75.2°, longitude 133.8°, diameter 320 km) were created too. These profiles show and characterize the height levels of the lunar craters and subpolar relief in detail (up to 100 m).

In general height profile makes clear imagination of surface and the main relief features. For instance, profile we created along 0° meridian (fig.9) characterizes the relief of the lunar nearside from -70° to -84° parallels. One can see the difference of heights from +1,7 km to -3 km. Further to the South Pole there are sudden falling up to -7 km and high mountain being at -86° parallel. The relative high of this mountain North slope is equal 5,7 km and the relative high of the South one is 7,3 km.

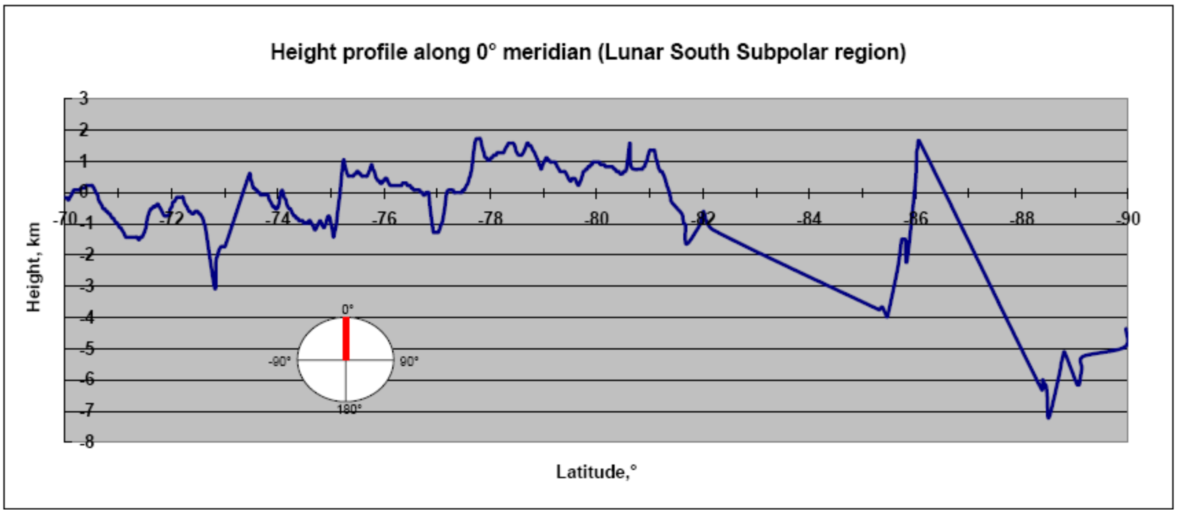


Fig.9 Height profile along 0° meridian (Lunar South Subpolar region)

The height profile of crater Schrödinger along -74° parallel is shown here for instance too (fig.10). This crater has smoothed rim, terrace and faults, the big external rim, ridge and a lot of hills at the rough bottom. The eastern mound has height of 1,3 km and the western one has height -2,5 km, that is crater Schrödinger has asymmetric rims. The internal ring of the ridges has raised rims. The relative height of this internal ring is equal 1 – 1,5 km.

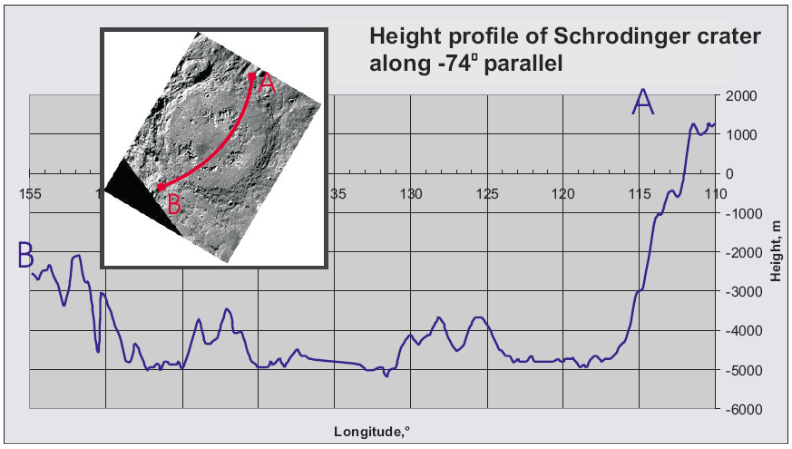


Fig.10 Height profile of crater Schrödinger

Authors [11] noticed, that indefinites of absolute subpolar heights fixing are still very essential. For example, in paper [14] it is proposed positive heights. For the rim of crater Shakleton being near the South Pole of the Moon radar data from the Earth surface [15] and authors [16] as well define positive heights of 1,6 km and 3±1 km accordingly while in papers [11] and [17] crater Shakleton has negative heights of -2,9 km и -3,9 km. That is why we decided to compare the absolute heights from Rosiek et.al. Lunar map [18] with the absolute heights of our map. The comparing was fulfilled using the height profiles along -90° and 90° meridians.

Paper [18] provides synopsis of a project to collect digital elevation models (DEM) from Clementine imagery. Topographic data were derived from overlapping nadir images collected by Clementine. This technique used stereo models formed by the imagery side lap of images from adjacent orbits. A relative elevation was derived at 1 km spacing and then the digital elevation model (DEM) was adjusted to fit the altimetry data or previously collected photogrammetric topographic data and contour lines for the lunar south pole were constructed (fragment of this map is shown at fig.11) [18].

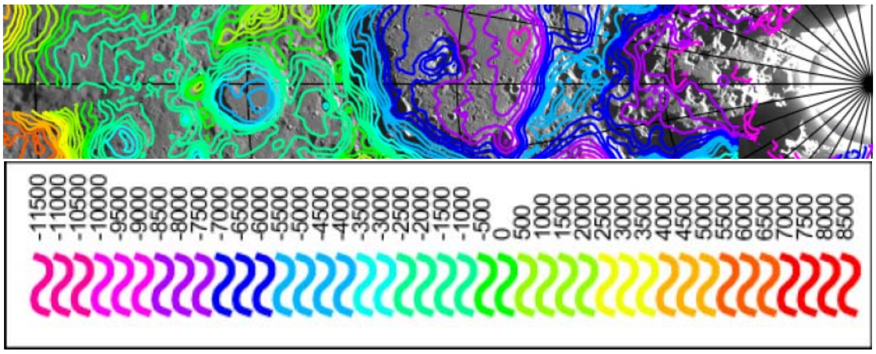


Fig.11 The part of the map [18] along meridian -90° and the height scale

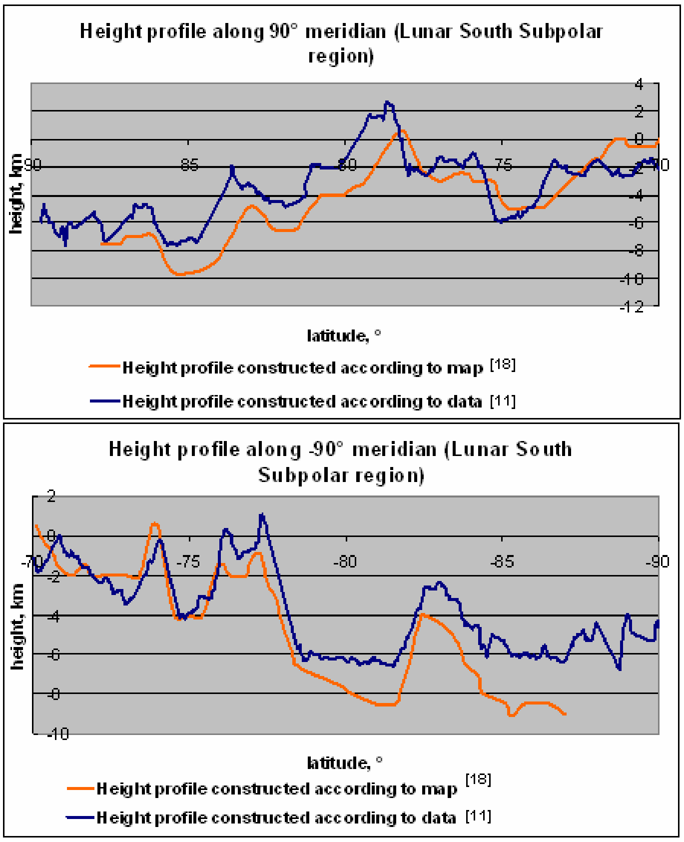


Fig.12 Height profiles along -90° and 90° meridians constructed according to map [18] and data [11]

The authors of the paper [18] marks: “This data is still being evaluated and edited. When compared to the Clementine altimetry data the data in figure 11 tends to be 1- 2 km higher at the edge, 65˚S. When compared to Tony Cook's data the data in figure 11 tends to be 1- 2 km lower at the pole, 90˚S. We are working on adapting the ISIS program EQUALIZE to adjust the errors.”

The comparison of height profiles (fig.12) constructed using our data with the profiles constructed using the map at fig.6 [18] showed the differences being of about 1 – 2 km having already noticed by authors [10] themselves.

3 OUTLOOK AND DISCUSSION

The presented work related to the compiling the hypsometric maps of terrestrial planets and their moons should be continued. At present, only the map of Mars was published. The map of Venus presented in this paper is still prepared for publication and the map of the Moon are compiled now. Global analysis and comparison of morphometric data obtained are planned with the aim to reveal the global relief properties of the terrestrial planets. Double names of relief features present a cartographic problem. A possibility is to set names in Latin writing similar to American and European maps. An alternative is setting both Russian and Latin names that lead to overloading this maps. But in this case it would make easier the perception of the map by Russian users. One more problem is the using the similar level scales for the Moon and other planets. Since the differences of heights at the different planets are not similar generally, it would be more opportune to use the original level scales, deriving from characteristic features of each planet.

It is obvious, that the investigation of relief by cartographic research method and GIS-technologies can give the great amount of information about the surface of planets, even in such small scale. Recently, the great explorations of Mars and other planets of Solar System are carried out by NASA and ESA. The enormous quantity of pictures and scientific data are achieved. Accordingly, the accuracy of creating maps could further be improved and opportunity of new investigations appears. A scientific problem we are particularly interested in and plan to research is the comparative planetology. It means the automatic creation of maps of the Earth, Mars, Venus and the Moon. Thus, comparative investigations of relief of these planets with the help of the created maps could be continued. The data obtained should give the opportunity for researching geologic history of these planets, which maybe could help to better understand some facts of the Earth history.

Based on processing of the Digital Elevation Model (DEM) created using the Clementine data [11] we compile the Lunar South Pole area database including latitudes, longitudes and heights for more than 4,5 millions points. At this moment we are compiling the Lunar South Pole region hypsometric map using this database. The next step of our work is the creation of the whole lunar surface hypsometric map. This map is planned to include in the Terrestrial hypsometric map series. For this series the Mars hypsometric map has been already published and the Venus hypsometric map is preparing for issue. However, using database we had obtained it became possible to fulfill the morphometric researches of the Lunar Subpolar relief even now. The detailed height profiles of different surface areas were constructed with the high resolution up to 100 m. The comparison of the profiles created using the data [11] and map [18] showed, that relief of South Subpolar region of the Moon is represented more detailed in paper [11], while absolute heights are differed from 1 to 2 km.

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