Planetary and Space Science ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

# Development of a new Phobos atlas based on Mars Express image data

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ARTICLE INFO

*Article history:*
Received 29 August 2014
Received in revised form
21 November 2014
Accepted 22 November 2014

*Keywords:*
Phobos
Atlas
Mars Express images
Planetary mapping
GIS

ABSTRACT

A new Phobos Atlas has been prepared, which includes a variety of thematic maps at various projections and scales, emphasizing dynamic topography, surface multispectral properties, geomorphology, as well as grooves- and crater statistics. The atlas benefits from innovative mapping techniques and recent results from Mars Express image processing: new derived control point networks, shape models and gravity field working models. A structure of the atlas is presented and some examples of the maps are shown. The Phobos Atlas can be useful for the future mission planning to the Martian satellite.



## 1. Overview of Phobos mapping in Russia

A detailed overview of the Phobos cartography from the first spacecraft photographs to new digital maps based on images from the Mars Express mission has been presented recently (Wählisch et al., 2014). Russia has a long-standing tradition in the mapping and studies of the Martian satellites. The first Russian map of Phobos was produced jointly at MIIGAiK and several institutions from Russian Academy of Science as early as 1988 during preparation and planning of the Phobos-1,–2 missions (1988). This map was produced using airbrush techniques and was based on images from NASA missions Mariner-9 and Viking-1. Also, a Phobos globe (scale 1: 85,000) was produced based on this map to visualize the 3-dimensional morphology of the body (Bugaevsky et al., 1992). To compile the map and globe, special map projections were developed, which represented the odd-shaped Phobos body in the form of a tri-axial ellipsoid (Bugaevsky, 1987). The map (1988) was used as a basis for mapping of Phobos in the “Atlas of Terrestrial planets and their satellites” (Shingareva et al., 1992), as well as in the Multilingual map series on celestial bodies (Shingareva et al., 2005).

To prepare for future international space missions to the Martian satellites, new Phobos maps were developed. These benefitted very much from the Mars Express mission (ESA/DLR/FU, G. Neukum) which has obtained a large volume of image data from the HRSC (High Resolution Stereo Camera), including its SRC (Super Resolution Channel) (Oberst et al., 2008), during more than 90 Phobos flybys (Witasse et al., 2014). Recently, a new Phobos Atlas with six separate maps, based on HRSC images, was published by DLR (German Aerospace Center) (Wählisch et al., 2014).

Various maps were also prepared in Russia on the basis of Mars Express data. For example, a topography map was published by the Sternberg Astronomical Institute (Shibanova et al., 2011) which was based upon the first new shape model of Phobos derived from images by Mars Express (Willner et al., 2010).

Other examples of new Phobos mapping efforts are the recently published (Karachevtseva et al., 2012) and the Phobos information system (Karachevtseva et al., 2014) which includes a new control point network, a global Digital Terrain Model (DTM) as well as local terrain models and orthomosaics, derived from high-resolution images (Zubarev et al., 2012; Oberst et al., 2014). These datasets were produced using specially developed software for small asteroidal bodies based on PHOTOMOD tools (http://www.racurs.ru/?page=59).

## 2. Structure of the atlas

Modern methods of image processing and GIS (Geographic Information System) provide scientists with the basis for detailed spatial analyses and high quality planetary mapping. Below we

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http://dx.doi.org/10.1016/j.pss.2014.11.024
0032-0633/

describe the cartographical conception and a structure of a new Phobos Atlas which has been created using ArcGIS tools (ESRI™). The atlas contains 42 Phobos thematic maps describing various aspects of the surface of the small odd-shaped body.

All maps are based on Mars Express data apart from one for which a mosaic provided by Phil Stook has been used (Stooke, 2012). This mosaic (http://sbn.psi.edu/pds/asteroid/MULTI_SA_MULTI_6_STOOKEMAPS_V2_0/document/m1phobos/phobos_cyl_dlr_control.jpg) is based on higher-resolution images obtained from the Viking spacecraft, Mars Global Surveyor and Mars Reconnaisance Orbiter. Due to the good resolution and uniform lighting, this mosaic is more suitable for automated crater detection (Uchaev D.V., et al., 2012). The distribution of craters based on automated crater detection, which is in good agreement with result of manual detection (Karachevtseva et al., 2014), is presented in the atlas (Fig.1).

The atlas consists of four chapters:

I. History of Phobos mapping.
II. Control point network, shape model and gravity field of Phobos.
III. GIS-analyses of Phobos' surface.
IV. Geomorphologic studies of Phobos.

The chapters include maps of various scales (see Table 1): global maps (1:300 000 and 1:250 000), regional maps (1:150 000, 1:120 000, 1: 75 000) and several local maps (1: 60 000 and 1:40 000) based on images with higher resolution, which present some regions in more detail.

The atlas contains results from recent Phobos research based on Mars Express data, for example, determination of shape parameters (Nadezdina and Zubarev, 2014), modeling and study of gravity field (Uchaev Dm. V., et al., 2013), surface compositional studies using HRSC color-channel data (Patsyn et al., 2012). The maps also present geomorphologic properties of surface: degradations of craters (Basilevsky et al., 2014), calculations of surface roughness (Karachevtseva et al., 2012), morphometric studies (Kokhanov et al., 2013), statistics of crater size-frequency distributions based on multi-fractal approach (Uchaev Dm. V., et al., 2012).

## 3. Coordinates and projections

Different coordinate systems are used to match the map content and atlas format, for which we choose a page size of A4 (320 mm × 220 mm). The maps are based on the sphere with radius 11.1 km according to IAU recommendations (Archinal et al., 2011).

The global topographic and thematic maps of the atlas are presented in a scale of 1: 250 000 in three sheets: the central area between ±60° parallels is projected in cylindrical conformal Mercator projection, polar areas from (±) 50° to (±) 90° are projected in azimuthal conformal (Stereographic) projection. The 20-degree grid is applied with west-positive longitude from 0° to 360°, and planetocentric /planetographic coordinates are given, as we used the sphere as a reference body for mapping.

One of the global maps shows contours based on geometric heights (Fig. 2). It is interesting to compare these with dynamic heights (Fig. 3), obtained from gravity field modelling (Uchaev Dm. V., et al., 2013), which are more relevant for studies of mass wasting effects and regolith mobility.

To show crater distribution derived from manual crater detection a Phobos surface map in five sheets has been prepared. Four sheets represent an area between ±60° parallels and projected in


**Fig. 1.** Layout of crater distribution map derived from automated crater detection, based upon Stooke mosaic (Stooke, 2012).

**Table 1**
List of maps.

| Chapter | Number | Name | Scale |
|---|---|---|---|
| I | 1. | Map of surface in modified Bugaevsky projection | 1:300,000 |
| II | 2. | Map of control point network errors | 1:250,000 |
| II | 3. | Map of images resolution | 1:250,000 |
| II | 4. | Global map of surface | 1:250,000 |
| II | 5. | Index of relief maps of Drunlo and Stickney | 1:250,000 |
| II | 6. | Map of crater Stickney | 1:60,000 |
| II | 7. | Map of crater Drunlo | 1:60,000 |
| II | 8. | Map of gravity potential | 1:250,000 |
| II | 9. | Map of centrifugal potential | 1:250,000 |
| II | 10. | Map of tidal potential | 1:250,000 |
| II | 11. | Map of attractive potential | 1:250,000 |
| II | 12. | Map of dynamic heights | 1:250,000 |
| III | 13. | Index of base map | 1:250,000 |
| III | 14–21 | Base map of surface (8 sheets) | 1:75,000 |
| III | 22. | Hypsometric map | 1:250,000 |
| III | 23. | Topographic map | 1:250,000 |
| III | 24. | Global map of crater distribution (Index map) | 1:250,000 |
| III | 25–30. | Map of crater distribution (5 sheets) | 1:150,000 and 1:120,000 |
| III | 31. | Map of crater density | 1:250,000 |
| III | 32. | Map of boulder distribution | 1:40,000 |
| III | 33. | Map of surface, based on mosaic, provided by Phil Stooke | 1:250,000 |
| III | 34. | Map of albedo. Blue channel | 1:250,000 |
| III | 35. | Map of albedo. Green channel | 1:250,000 |
| III | 36. | Map of albedo. Red channel | 1:250,000 |
| III | 37. | Map of albedo. Index NIR | 1:250,000 |
| III | 38. | Map of albedo. Index V/NIR | 1:250,000 |
| IV | 39. | Geomorphological map | 1:250,000 |
| IV | 40. | Map of morphological zoning | 1:250,000 |
| IV | 41. | Map of slopes | 1:250,000 |
| IV | 42. | Map of roughness | 1:250,000 |

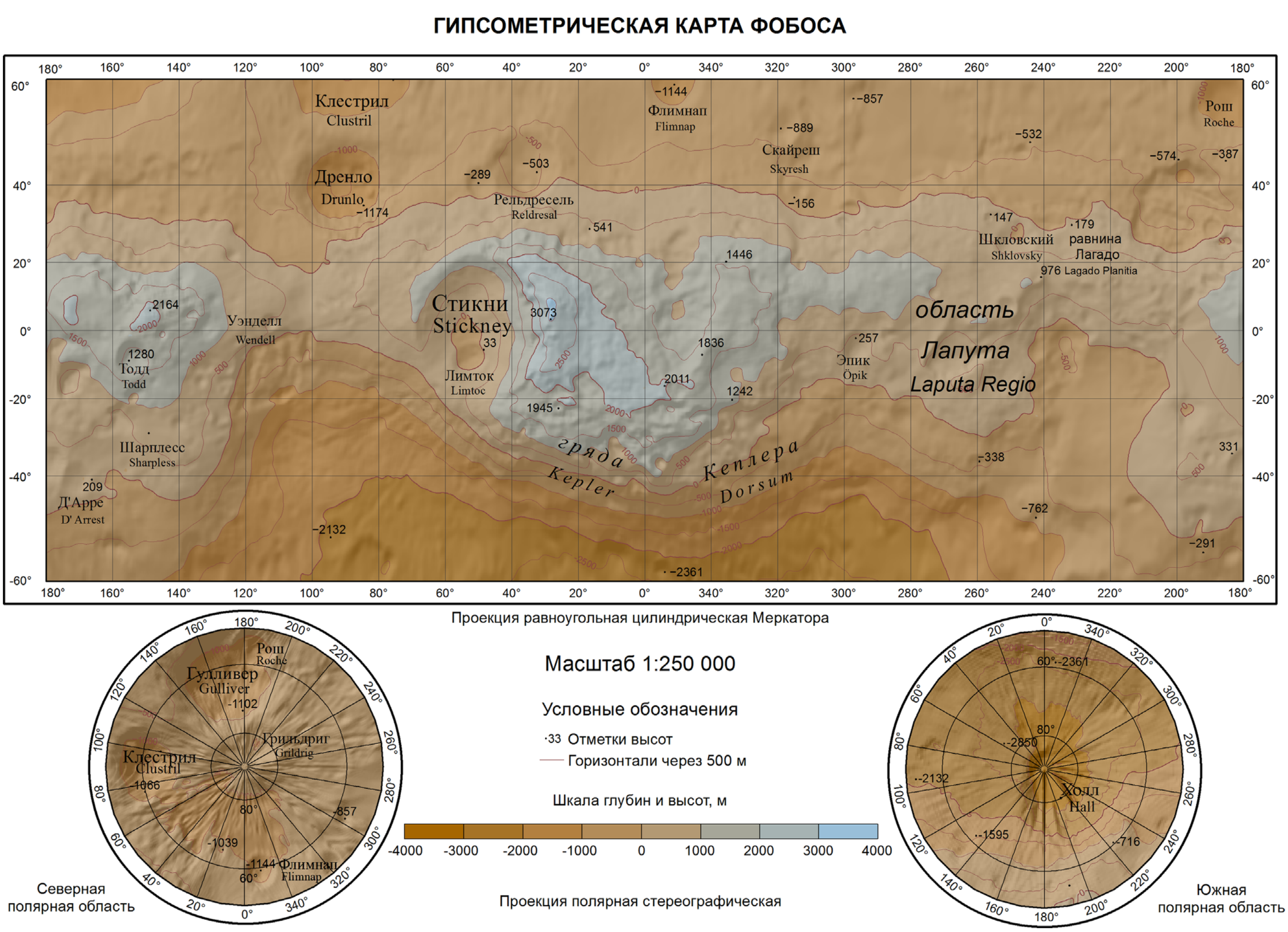


**Fig. 2.** Layout of hypsometric map, derived from the DTM; background: shaded relief produced from geometric heights.

Please cite this article as: Karachevtseva, I., et al., Development of a new Phobos atlas based on Mars Express image data. Planetary and Space Science (2015), http://dx.doi.org/10.1016/j.pss.2014.11.024

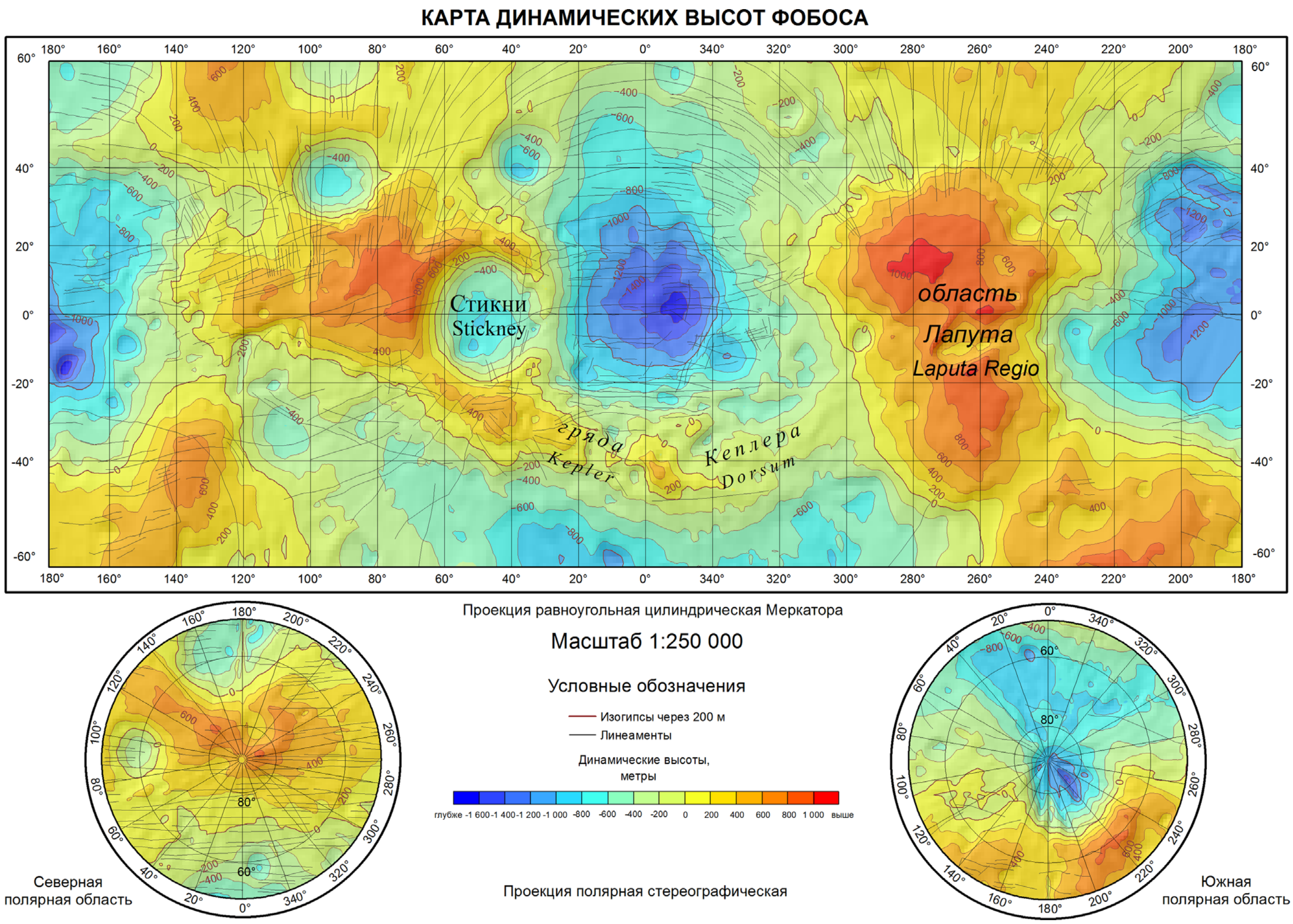


**Fig. 3.** Layout of map of dynamic heights with Phobos lineaments; background: shaded relief produced from dynamic heights.

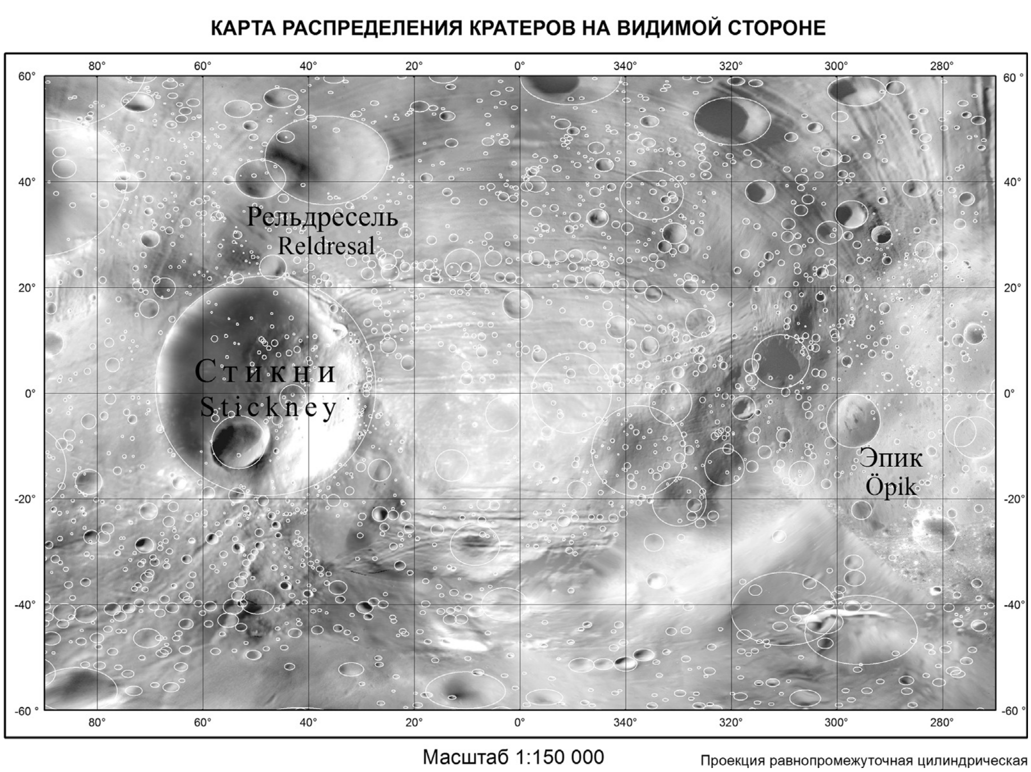


**Fig. 4.** Layout of map of the distribution of craters (5 sheets). Sheet for the near side of Phobos.

Please cite this article as: Karachevtseva, I., et al., Development of a new Phobos atlas based on Mars Express image data. Planetary and Space Science (2015), http://dx.doi.org/10.1016/j.pss.2014.11.024

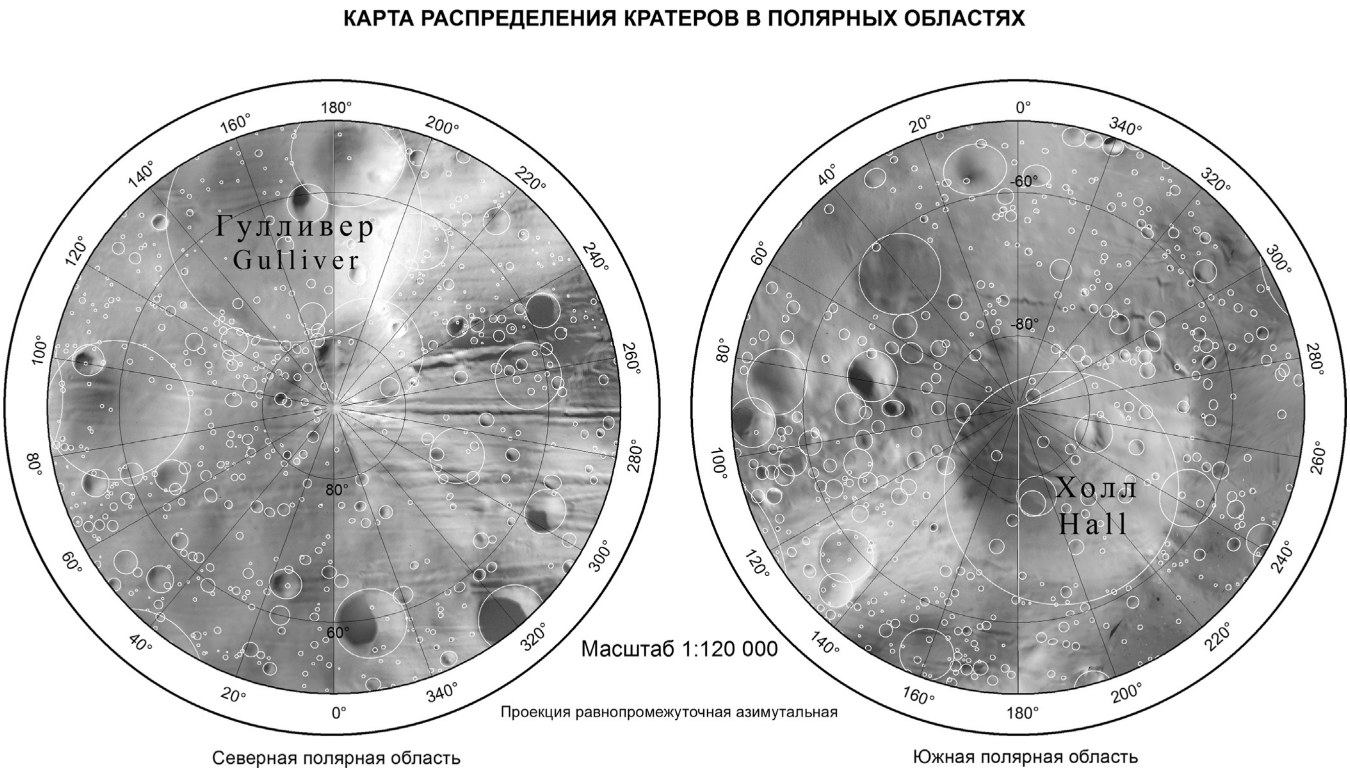


**Fig. 5.** Layout of map of the distribution of craters (5 sheets). Sheet for polar areas of Phobos.

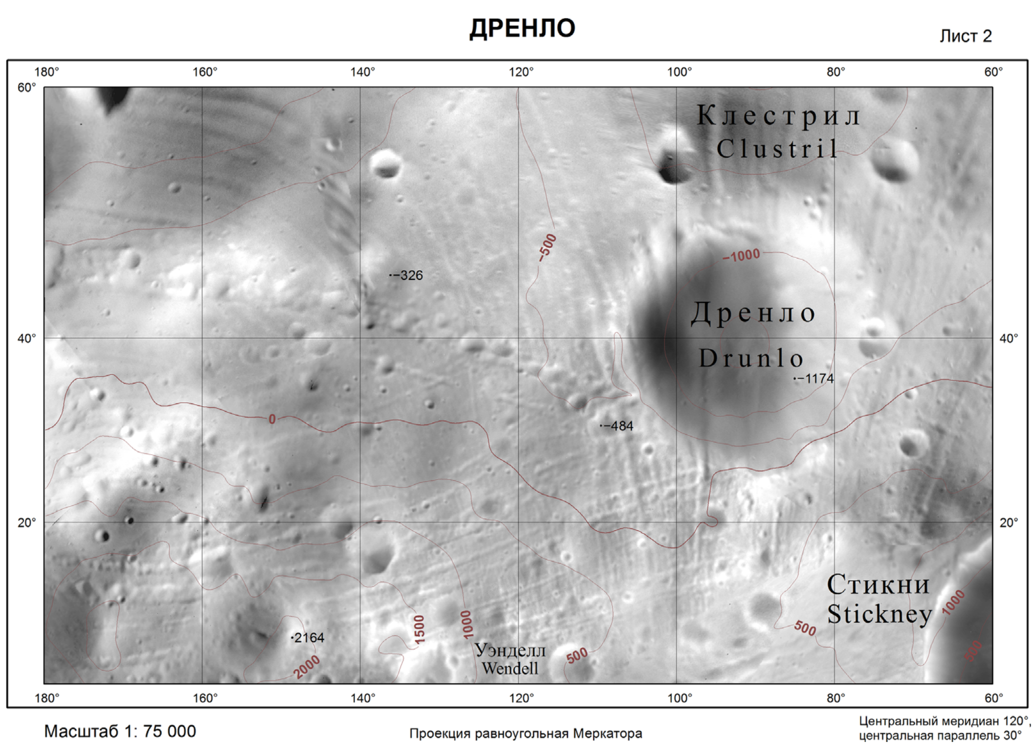


**Fig. 6.** Layout of base map of the surface of Phobos (8 sheets). Sheet # 2 (Drunlo).

Mercator projection with the main parallel and main meridian in the center of each sheet (Fig. 4). The fifth sheet demonstrates the polar areas, for which the same Stereographic projection, as described for global maps, is used (Fig. 5).

Besides global and regional maps we also compiled large-scale topographic maps (1: 75 000), divided into eight sheets (Fig. 6) as has been suggested for planetary cartography applications (Greeley and Batson, 1990).

To maintain continuity and heritage of previous Russian Phobos maps, as described above (see Section 1), one of the maps (Fig. 7) is given in modified Bugaevsky projection upon the three-axial ellipsoid. Parameters of the ellipsoid (axis: $a=13.24$ km, $b=11.49$ km, $c=9.48$ km) were calculated from statistics of new 3D control points

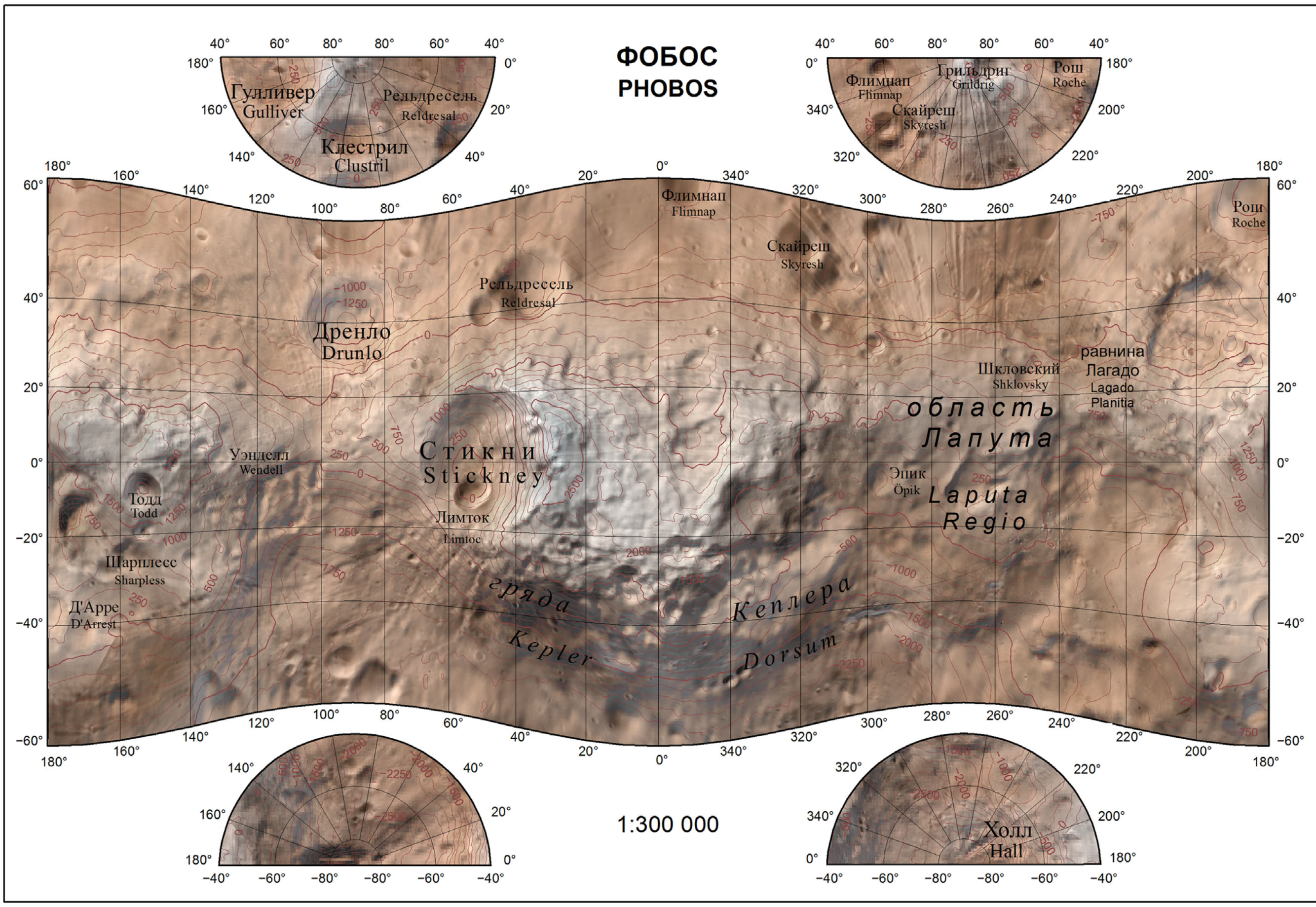


**Fig. 7.** Layout of new Phobos surface map, based upon the original 5-sheets layout, suggested by Kira Shingareva (1988), including the equatorial area in a modified Bugaevsky projection, and polar areas in azimuthal projection upon three-axial ellipsoid. Background: artificial airbrush map produced with ArcGIS tools and based on a Phobos DTM derived from Mars Express SRC- stereoimages (Nadezhdina and Zubarev, 2014).

(Nadezdina and Zubarev, 2014), and are slightly different from the IAU three-axial ellipsoid ($a=13.0$ km, $b=11.4$ km, $c=9.1$ km).

The Gazetteer of Planetary Nomenclature (http://planetarynames.wr.usgs.gov/Page/PHOBOS/target), which contains 20 named geologic features, has been used for the designation of landforms and areas. Although the atlas is prepared in Russian, feature names will be presented in bilingual form (Russian and English).

## 4. Conclusions

We have developed the layout for a new Phobos Atlas which consists of various thematic maps in different scales. For compilation of the maps we have used new computational analysis techniques and GIS (Karachevtseva et al., 2014). New control point networks (Oberst et al., 2014), and new shape models formed the basis of the atlas.

Color codes in the surface Phobos maps, which were created specifically for the atlas, are very much different from the standard artificial color codes that are used. The maps (e.g. Fig.7) reflect the natural color of the surface as obtained by the spectral channels of the High Resolution Stereo Camera (HRSC) on Mars Express (Fig. 8). Furthermore, we combined the original projections and map layouts in historic maps with today's modern image processing technologies (Fig.7). Most importantly, we do not rely on a printed atlas only, but use web-based techniques for open access to maps and data sources. The digital versions of the Phobos maps from the atlas will be placed into the MIIGAiK Extraterrestrial Laboratory web-page (http://mexlab.miigaik.ru/eng/).

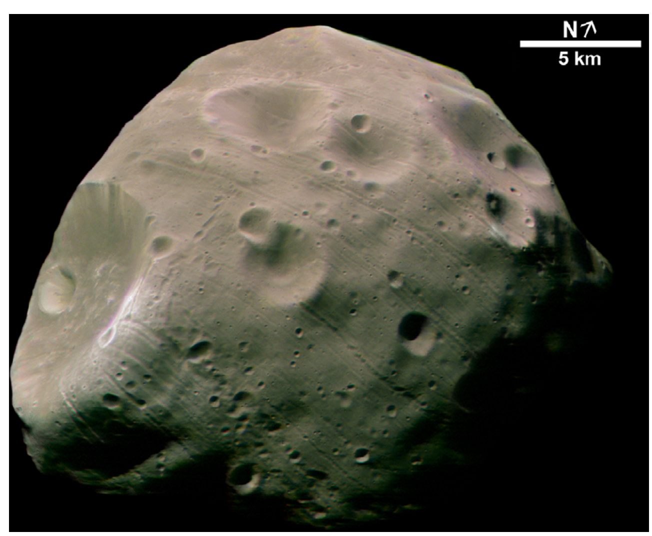


**Fig. 8.** Mars Express HRSC color image (www.esa.int/spaceinimages/Images/2004/11/Phobos_in_colour_close-up) used for the color scheme of the surface maps.

Data products which were used for the mapping also will be available at the MExLab Geo-portal (http://cartsrv.mexlab.ru/geoportal/) (Karachevtseva et al., 2014).

As the Mars Express mission continues, we are going to update global orthomosaics and basic maps of Phobos as new images with higher resolutions, taken under more favorable illumination conditions, become available. The Phobos maps will be useful for the planning of future Phobos exploration, as realized, for example, by the "Boomerang" mission, which is being planned jointly by ROSKOSMOS and ESA for launch in 2022.

## Acknowledgments

The authors gratefully acknowledge constructive reading and comments by M. Wählisch (DLR) and E. Cherepanova (MIIGAiK). The Phobos Atlas developed at MIIGAiK and supported by the Russian Science Foundation, project # 14–22-00197.

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