Hebrus Valles—The Mars Exploration Zone Map

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Abstract Hebrus Valles is one of the 47 candidate Exploration Zones for the first human landing mission of NASA on Mars. The area meets specified criteria for a scientific expedition—among others, it has potential for the water and other resources necessary to perform such a mission. The aim of the project described in this paper was to attempt to create a specialized map for Mars explorers working in the field. The map of Hebrus Valles proposes locations for the landing zone, habitation zone, regions of interests, and traverses. The proposed map also contains descriptions of the geomorphological features of the landscape and warnings about surface hazards. When combined, these elements produce a surface operation map with special requirements that are unlike any map produced on Earth, perhaps the closest analog is hiking maps. This paper presents a detailed characterization of the map, as well as projecting methodology. The process of panchromatic sharpening is the most important part of mapping, mainly due to the effective fusion between a high resolution digital elevation model and a low-resolution color image. A description of tasks carried out using the cartographic tools JMARS, ArcMap and Photoshop is also included. In conclusion, this paper introduces possibilities of implementation of an interactive variant of the map and provides ideas that may be applicable for designing a cartographic system for future operations on the surface of another planet.

Keywords Mars · Exploration zone · Hebrus Valles · Planetary map · Planetary cartography

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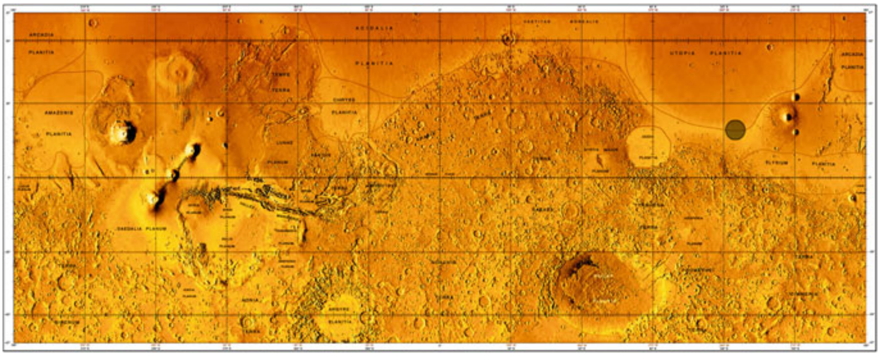

Fig. 1 Approximate boundaries for Mars regional feature names with selected Hebrus Valles region *circled* in *black*. The map is based on the MOLA digital elevation model with an adjusted color scale. (*Source* Smith et al. 2001)

1 Introduction—Basic Information About Hebrus Valles

Hebrus Valles is a region of Mars on the southern border of Utopia Planitia (see Fig. 1), which is the largest impact plain on the planet (Thomson and Head 2001). The name Hebrus Valles comes from Earth's Balkan River. The trough and valley system extends from south-east to north-west direction for about 250 km. The channels formed by fluid erosion, which emerged from the surface or underground rocks (Christiansen and Hoppin 1987), are characterized by several subchannels and streamlined islands.

Hebrus Valles is located near 19.88°N latitude and 126.74°E longitude (Gazetteer of Planetary Nomenclature 2016), so it is positioned closer to the equator than to the pole of Mars. The area is situated approximately 3000 m below the zero elevation of the Mars surface and the depression extends in the north–east direction.

2 Motivation and Goals

The basic goal of the Hebrus Valles Map is to visualize the Exploration Zone (EZ) surface in a way that could be helpful for future astronauts. There are 47 candidates for EZs (Bussey and Hoffman 2016) and this map is the best medium to show the most valuable characteristics of the site. Another purpose of the map is to allow insightful evaluation of the EZ and assist scientists in their comparison EZ candidates.

Furthermore, the aim of this paper is to introduce cartographic methods or processes which facilitated the development and projection of the Hebrus Valles Map. Additional goals are to explain and describe all of the map elements and to detail possible uses in the field. Finally, this paper suggests application of the map for new technologies (touch screens) and proposed interactive options for the map's use.

3 Exploration Zone Criteria

The EZ is an aggregation of regions of interests (ROIs) placed within 100 km of the landing zone (LZ). The main factors for evaluating EZ candidates, in brief, are as follows:

- the presence of resources that would sustain life of future astronauts in Martian conditions—this includes water in any form (hydrated minerals, ice deposits) and other materials needed for habitation
- the possibility of finding remnants of life in any form in past or present state
- achievable new scientific data which would impact on our knowledge about the planet
- a location between 50°N and 50°S latitude
- terrain located not higher than 2000 m above zero reference surface elevation
- 25 km^2 of surface which is not inclined more than 10°
- area with relatively small number of hazards (e.g., mountains, craters concentration)
- zone shouldn't have thick dust deposits (Bussey and Hoffman 2016)

4 Exploration Zone Map Symbology

The EZ map is not a usual map. The objects, places, buildings, and symbols that the EZ map contains are adjusted for the needs of the first planetary explorers. These necessary objects are defined in the EZ parameters (Bussey and Hoffmann 2016).

The locations and positions of building structures displayed on the Hebrus Valles Map may be arranged differently in order to adjust to the mission. The position of the Science Regions of Interests (SROIs), Resource Regions of Interests (RROIs), Special Regions of Interests (SRs), Landing Sites (LSs), and paths are based on the original EZ proposal (Davila et al. 2015) and other studies (Rodriguez et al. 2012) in which the authors identify the points of significant regions. However, many points were positioned by the author of this map and paper after a thorough analysis of relevant information and maps.

The most important considerations for future astronauts working in the field are surface morphology, potential hazards, building structures of the mission base, and waypoints (places) that may potentially be visited. The Hebrus Valles Map has octahedral symbols that provides information about each specific location.

Table 1 Symbols of the Hebrus Valles Exploration Zone Map

No.	Symbol	Description
1		Landing Sites (symbol occurs also as LS) and Habitation Zone: These areas are places appropriate to spacecraft landing and base establishment. The Habitation Zone is a field station including greenhouse for farming, a power zone, and rover parking
2		Science Region of Interest: This area is actively forming or changing today, erosion is actively exposing old materials. Additionally, the formation of the surface material involved water (sediments of rivers, lakes, or glaciers), and materials may be characterized by fossilized lifeforms
3		Resource Region of Interest: This area contain water in all forms, surface or shallow subsurface ice, slope lineae, hydrated minerals, glaciers, hydrated dunes, and atmospheric H_2O. Geology in these areas may be characterized by cobble sized rocks, regolith (soil), and material that contains iron, aluminum, and silicon ready to be mined by automated systems
4		Special Region: This is the area where terrestrial microorganisms are capable of replicating. These regions should be avoided by humans but can be studied by sterilized robots
5		Paths and Roads: Some of the tracks may be paved for faster transportation
6		Greenhouses for Plant Cultivation: This is the place where plants are grown either hydroponically under artificial light or in local regolith using natural lighting
7		Habitation Zone: This is the area where explorers will have their living quarters
8		Power Zone: Power will be produced in this area and sent to other structures
9		In Situ Resource Utilization: Area where waste will be recycled or destroyed. Encountered materials will also be stored and processed to meet the needs of the mission (Sacksteder and Sanders 2007)

The shape provides a modern method of identifying the locations as well as easy access to details about each place. The labels used on the symbols are projected in Century Gothic font. In order to clearly identify the locations, a unique color of symbology is used for each place (for example, green for Greenhouses, black for Landing Site). The symbols used in the map are explained below in Table 1.

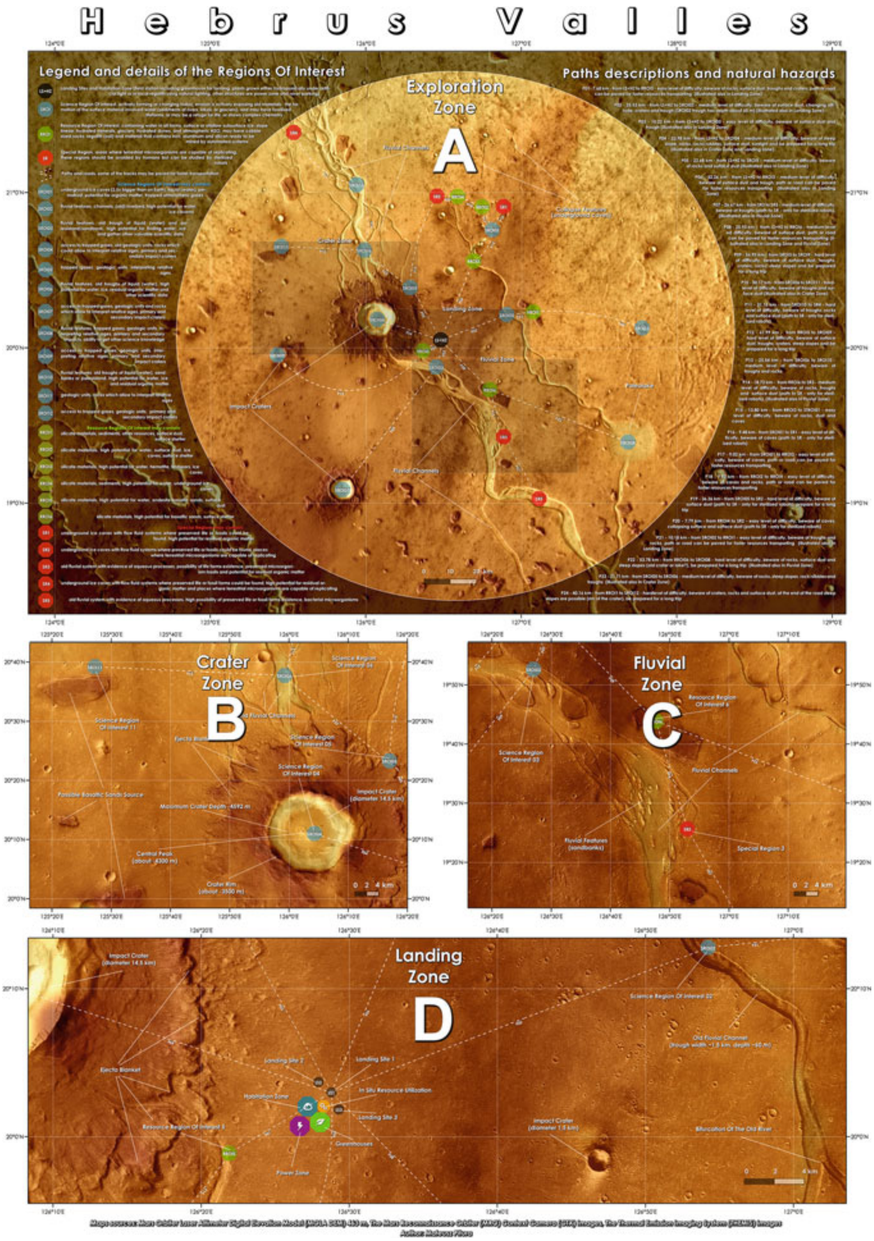

Fig. 2 Full Hebrus Valles Exploration Zone Map layout with signatures

5 Paths (Traverses)

The tracks illustrated on the Hebrus Valles Map are traverses mostly for rovers from the LZ to the SROIs, RROIs, and SRs. Routes were chosen by appointing the shortest possible path across the Mars surface to the destinations. The general method of track selection involved a detailed study of the terrain of Mars. In order to determine and review the tracks, maps from JMARS software were used, including a dust cover index map (Ruff and Christensen 2002), MOLA slope map (Smith et al. 1999), thermal inertia map (Christensen and Moore 1992), rock abundance map (Nowicki and Christensen 2007) and many others. The paths were created primarily on lines where the surface of Mars was clear of obstacles. The length of each path was measured in kilometers using ArcMap.

The paths were divided into easy, medium, and hard levels depending on the hazards that astronauts could encounter and on the length of the track. The levels of difficulty are provided on the map to aid explorers and vehicles (rovers) acting as transporters. The details of the path difficulty levels are as follows:

- Easy—tracks under 15 km. The road does not require special preparations. Obstacles are of a minimum level of difficulty and there is a possibility of surface dust and small craters. Slopes should be under 10°.
- Medium—tracks from 15 to 30 km. The road necessitates preparation of the rover (checking the amount of fuel). Obstacles including rocks, rock rubbles, small craters, surface dust, and troughs will require more attention. Slopes are greater than 10°.
- Hard—tracks above 30 km. The condition of the road necessitates special preparations (rover tanking) and the use of scientific equipment. Some hazards may be present, including steep slopes, rocks greater than 30 cm in size which could present an obstacle for rovers (Bussey and Hoffman 2016), large rock formations, craters, surface dust, troughs, ice, and depressions.

The longest route is 61.99 km (P12) and is marked as hard due to the fact that it would be a long and tiring journey. Some warnings related to geomorphological features of the landscape are also included in the traverse characterizations. Descriptions of the paths depicted on the map are listed on the right side of the main EZ illustration (see Fig. 2).

6 Hebrus Valles Exploration Zone Map Detailed Description

Hebrus Valles was chosen for EZ because of its great potential for the presence of water and remnants of life (Davila et al. 2015). The fluvial-like structures in the center of the zone suggest that fluid once flowed on the surface of the terrain (Schulze-Makuch et al. 2016). What is more, the Hebrus Valles region is rich in impact craters, which will allow astronauts to reach older geological structures of Mars and expand their knowledge about its history. An important concern in planetary cartography is that the map visualize at least three themes: base image, grid, and nomenclature (Hargitai 2005), which give the astronaut the ability to orient himself in the field. The Hebrus Valles Map illustrates everything future Mars explorers will need to plan their journeys and investigate the EZ: terrain as a base image, grids, elements (symbols), paths, and nomenclature referring to the surface. Furthermore, the map has magnified the most important regions for scientists.

The Hebrus Valles Map is divided into four sections (see Fig. 2). The layout contains: (A) the main EZ map in the upper section; (B) a magnified map of the Crater Zone, in the middle on the left; (C) a magnified map of the Fluvial Zone, in the middle on the right; (D) a magnified map of the Landing Zone in the bottom part. The sections are described below:

- A—the main map, area of EZ, 100 km radius from the center point (126.38°E, 20.05°N). The map provides special symbols which are connected to RROIs, SROIs, SRs, LZs, paths, and provides text referencing geomorphological structures. What is more, there are transparent squares covering the magnified areas of the maps below. A legend with significant descriptions is located on the left and right side of the map. A simple, linear scale is situated on the bottom of the map.
- B—the Crater Zone, which is an interesting area for scientists. The map shows symbols (SROIs, paths), text referencing geomorphological structures and other information. A simple, linear scale is situated in the bottom right corner of the map.
- C—the Fluvial Zone, which is an interesting area for scientists. The map shows symbols (SROIs, paths), text referencing geomorphological structures and other information. A simple, linear scale is situated in the bottom right corner of the map.
- D—the Landing Zone, which is the main area of the mission. The map shows symbols (RROIs, SROIs, SRs, paths, and also Habitation Zone, Power Zone, Greenhouses, and In Situ Resource Utilization), text referencing geomorphological structures and other information. A simple, linear scale is situated in the bottom right corner of the map.

All of the maps mentioned above have grids based on a coordinate system named the Interplanetary Mars 2000 Sphere, projection Plate Carree.

The color scale of the EZ Map was selected according to Mars studied hues (see Fig. 3)—yellow (sand) and bronze (Maki et al. 1999). Bronzes characterize the highest elevations on the map (from −3600 to −3400 m) and the yellow-sand colors illustrate the lowlands (from −3700 to −4500 m). By analyzing the map terrain, it can be concluded that the Hebrus Valles region is declining in the north–west and north–east directions. Moreover, from north (north–east) to south, a characteristic wedge-shaped (triangular) ridge is present.

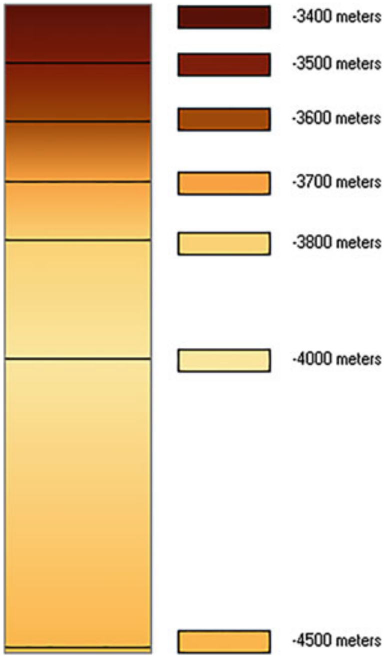

Fig. 3 Color scale used for the Hebrus Valles Exploration Zone Map

7 Creation of the Map, Methodology

The Hebrus Valles Map was designed in three stages and using three different applications. First of all, for finding, viewing, and reviewing EZs, JMARS version 3.5.3 (Christensen et al. 2009) was used. The mapping process was completed using ArcGIS for Desktop (in version 10.2.2). The third part of the work involved performing post-mapping adjustments, modifying the legend, providing descriptions, and adding details in Photoshop CS6.

First, the images of the Hebrus Valles region from The Thermal Emission Imaging System (THEMIS) (Hill et al. 2014) and The Context Camera (CTX) (Malin et al. 2007) instruments were exported in high resolution to raster files from JMARS software. Another common visualization of Mars, the Mars Orbiter Laser Altimeter (MOLA) (Smith et al. 2001) digital elevation model, was obtained from the official source and used to create the main EZ Map.

The first steps in ArcMap were related to rectifying all of the maps exported from JMARS to the Interplanetary Mars 2000 Sphere coordinate system (see Fig. 4). Before that, a WMS (Web Map Service) map was added to layers as a reference. Adjustments were made using the ArcMap Georeferencing Tool.

The next step involved importing the MOLA digital elevation model to ArcMap and adjusting the coordinate system. Clipping to Hebrus Valles zone was necessary to minimize excessive use of computer memory. Then, color symbology was used on a digital elevation model and adjusted for optimum visualization (see Fig. 4).

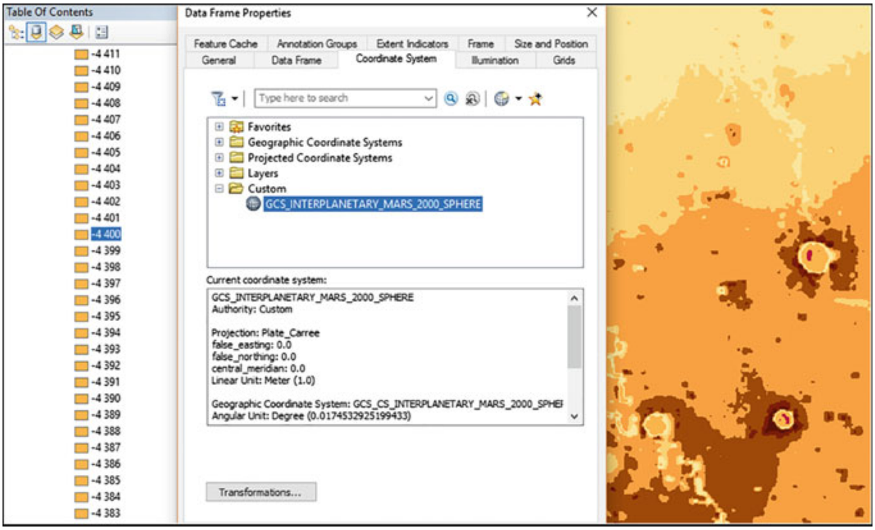

Fig. 4 Coordinate system of the map with color symbology in ArcMap

An important part of creating the map was using the pansharpening tool in ArcMap. Pansharpening (or panchromatic sharpening) is a fusion between two pictures which allows the user to obtain a higher resolution image (Xu et al. 2014). In this case, the No Alteration of Grayscale or Intensity (NAGI) method of pansharpening was used (Nagi 2012). This method uses a regular color distribution and an adjusted gamma value—such technique allows the user to achieve more effective image fusion. After use of the pansharpening tool, images were modified for best performance by changing contrast, color intensity and sharpness (see Fig. 5).

When the main base map was prepared, symbols and others features were created as shape files: LZ+HZ, RROI, SROI, SR and paths. The positions of the points and lines were based on proposed regions of interest (Davila et al. 2015) or, in most cases, on geomorphology, geology, relief of terrain, and many JMARS statistic maps.

A 200 km circle diameter was achieved by inserting the point of Hebrus Valles (126.38°E, 20.05°N) provided by the proposers of the EZ (Davila et al. 2015) and using a buffer tool in ArcMap. The result was a circle with a 100 km radius extending from the center point.

The last stage of the ArcMap process involved preparing the map for printing: creating frame, adjusting scale to 1:800 000 (scale to include all of the EZ), creating grid coordinates and legend with figures to use in later mapping in Photoshop.

Almost all of the above-referenced steps were also applied to the other magnified maps: the Crater Zone, the Fluvial Zone, and the Landing Zone. In contrast, however, the Crater Zone and the Fluvial Zone frames were scaled to 1:350 000. The Landing Zone, the most magnified section of the map, was scaled to 1:140 000.

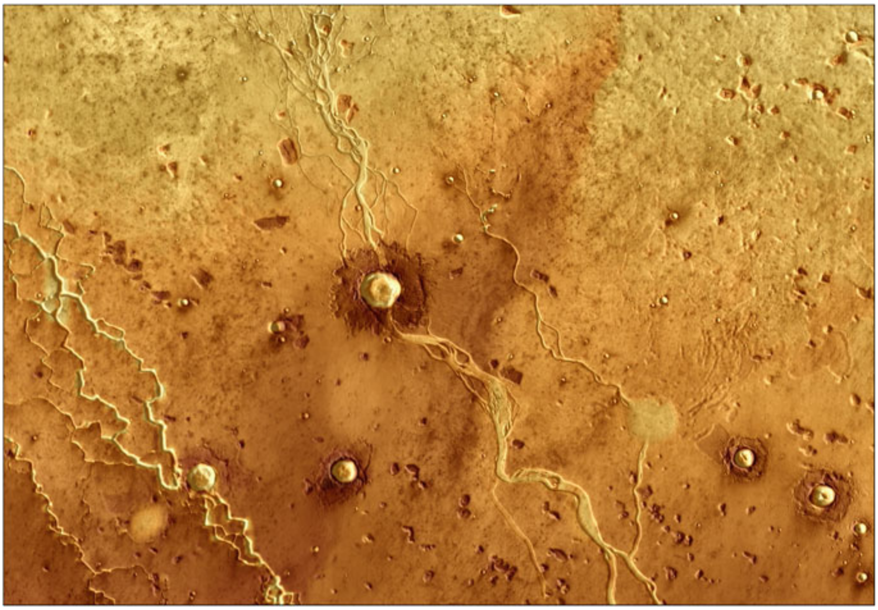

Fig. 5 Final result of the NAGI pansharpening method. Depicted is MOLA DEM in fusion with adjusted color symbology

There was also a need to create new shape files for the Landing Site, Habitation Zone, Greenhouses, Power Zone, and In Situ Resource Utilization areas.

Post-mapping processing was completed using Photoshop, where the transparency of the legend was created. Geomorphological annotations with arrows were also created in this mapping stage. Further actions focused on developing the scales and the arrangement of the map sections. Lastly, color correction was completed using a curve filter.

8 Map Format and Adapting to New Technologies

The Hebrus Valles Map is projected to be printed on paper in portrait mode, so that all four of the sections may be viewed. A remaining question is whether the astronauts should have paper maps with them in the field. Today, digital maps are widely used around the world (including maps of planetary bodies) and their significance has increased in recent years. Maps on screens have many advantages, for example they have the ability to illustrate multiple map sheets, they are interactive (ability to zooming, locating, and tracking), and they can be updated quickly and easily. However, despite the many benefits of digital maps, paper maps also have their advantages. Most of all, easy access to maps is fundamental in the field and electronic maps are not always available, such as when a power source is not present or the device projecting the map is not working. A paper map does not depend on electricity, which could be a crucial factor in a hostile, alien environment.

Additionally, paper is lightweight, it can be folded into a small size and expanded for viewing, and it enables users to visualize large areas in high resolution at once (large screens are generally not available for field work, however, future technologies may develop virtual glasses that project maps to the entire field of view, or in an augmented reality environment). Hence, on a paper map more details may be included for a larger area. Furthermore, the continuous availability of a paper map in emergency situations can be mission critical. Therefore, paper maps should be essential components of an astronaut's field equipment—in fact, the success of the mission could depend on the availability of a paper map.

Above all, the Hebrus Valles Map has implications and potential for new technologies (mainly touch screens). For example, using touch screens, astronauts could zoom into specific regions of the map on their electronic computer pads by selecting the area to be magnified. This feature would allow astronauts to see more details of a specified region. Examples of this solution are available on the EZ section of the Hebrus Valles Map where transparent black rectangles are present (see Fig. 6).

Additionally, the feature of selecting and combining different layers is a common component of interactive maps. Until now, we have had numerous maps of the Mars surface that would be necessary for future astronauts. Furthermore, every computer containing the map ought to include a real-time information system that

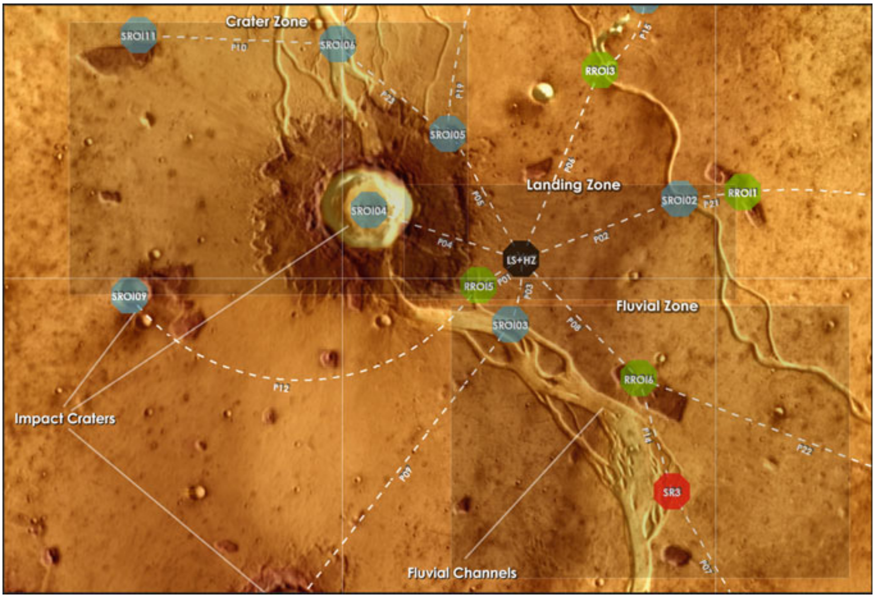

Fig. 6 Transparent *black rectangles* on the Hebrus Valles Map selecting the magnified areas

provides details about current surface conditions—this could be accomplished through the map image and through an alarm received by the astronaut.

Another idea is to enable astronauts to create profile lines to display terrain morphology along specified tracks and identify what hazards are expected on the road. Further analysis of terrain lying on the line would require knowledge about geology and rock abundance—implementing such an option would result in better route planning and would improve the safety of explorers.

What is more, an essential feature would be the ability to choose a point of interest, view the legend and significant information near it on the map. Rather than limiting this only to SROIs, ROIs, SRs, and other symbols, all of the map terrain could be interactive.

Finally, the most important and useful option is positioning an astronaut in real time—using local transmitters for triangulation or orbiting spacecrafts—and orienting the area based on the direction the astronaut is looking. The location of the astronauts should also be available and visible on maps for others in the Habitation Zone.

9 Summary

The Hebrus Valles Map displays one of the 47 Exploration Zones that could be the area of the first human steps on Mars. Future explorers will need access to all of the latest mapping technologies in order to gain invaluable knowledge about our universe. The detailed Exploration Zone visualization is crucial for mission planning, as well as for safety on the surface of Mars. Methods and software used for mapping (JMARS, ArcMap, and Photoshop) apply the techniques of modern cartography and ensure that maps will be sufficiently detailed. Moreover, the use of the map on computers or other modern equipment would enhance the map's usefulness to astronauts. Finally, the addition of interactive and support elements to the map should also be considered in order to provide astronauts with the best mapping tools.

This map could be successfully used in the field, where astronauts will make efforts to travel and survive in unfavorable environment. In order to plan traverses and journeys for revealing secrets of Mars, astronauts will need a map that includes details such as distances, points of interest, dangerous places, and safe paths—everything that the Hebrus Valles Map illustrates.

The success of the mission is the priority. Cartographers can help astronauts by providing them as many significant details as can be found and by presenting this important information in an easily accessible way.

The Hebrus Valles Mars Exploration Zone Map is available online at http://www.hebrusvalles.com.

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