Color-coded Topography and Shaded Relief Maps of the Lunar Hemispheres. M.R. Rosiek, R. Kirk, E. Howington-Kraus, U.S. Geological Survey, Astrogeology Program, 2255 N. Gemini Dr. Flagstaff, AZ 86001, mrosiek@usgs.gov.

Introduction: A new set of U.S. Geological Survey 1:10 million scale lunar maps combines color-coded topography with shaded relief data and nomenclature. The 3-sheet set of maps portrays two hemispheres per sheet; Sheet 1 shows the near side and far side hemispheres, Sheet 2 the west and east hemispheres, and Sheet 3 the north and south hemispheres. Topographic data are from the Clementine laser altimeter and photogrammetric data collected from Clementine images. The shaded relief data, previously published as U.S. Geological Survey maps, were updated to fill in void areas and were aligned with the Clementine digital image mosaic. Nomenclature provides a general orientation of prominent features. This set of maps provides a synoptic overview of lunar topography data.

Adopted Figure: The figure for the Moon, used for the computation of the map projection, is a sphere with a radius of 1737.4 km [1]. Because the Moon has no surface water, and hence no sea level, the datum (the 0-km contour) for elevations is defined as the radius of 1737.4 km. Coordinates are based on the mean-Earth/polar-axis (M.E.) coordinates system, the z axis is the axis of the Moon's rotation, and the x axis is the mean-Earth direction. The center of mass is the origin of the coordinate system [2]. The equator lies in the x-y plane and the prime meridian lies in the x-z plane with east longitude values being positive.

Projection: The projection is Lambert Azimuthal Equal Area Projection. The scale factor at the central latitude and central longitude point is 1:10,000,000.

Control: The original control for the shaded relief maps was based on horizontal control from either the Lunar Positional Reference of 1974 [3] or the Apollo control system of 1973. Positional discrepancies as large as 25 km at map scale existed in the original shaded relief base. To improve the accuracy, digital shaded relief data were aligned with a mosaic produced from Clementine images [4,5]. This alignment process consisted of picking points of features that were visible in both the shaded relief data and the Clementine mosaic. To accomplish this, the files were divided into three areas: north pole, equatorial region, and south pole. They were aligned first in the equatorial region and then in the polar regions. Within the equatorial region, an area from 60° S. to 60° N., approximately 1000 points were picked. Within the north polar region, an area from 57° N. to 90° N., approximately 1900 points were picked. Within the south polar region, an area from 57° S. to 90° S., approximately 1100 points were picked. These points were used to warp the shaded relief map to match the Clementine mosaic. The Clementine mosaic has a positional accuracy of 500 m.

Vertical control is based on the Clementine laser altimeter that collected data between 79° S. and 81° N. The along-track spacing varied: over some smooth mare surfaces an along-track spacing of 20 km was achieved; where the instrument lost lock over some rough highland terrain, the spacing degraded to 100 km. The across-track spacing was based on the orbital track and is approximately 60 km at the equator and less elsewhere. Elevation values were collected at 72,548 points by the Clementine laser altimeter. The estimated vertical accuracy of points collected by the Clementine laser altimeter is 130 m [6].

Because the Clementine laser altimeter did not collect data over the lunar north or south pole; topographic data were collected photogrammetrically to fill in these gaps. Vertical control, for the photogrammetric data, was established by using the Clementine laser altimeter data at the outer edge of the circular polar areas and the imagery was used to bridge control and fill in the central part of the circle. [7] The expected precision of points collected photogrammetrically is 180 m. [8]. Further discussion of the photogrammetric topographic data can be found in the topographic data section of this abstract.

Image Base: The shaded relief data were originally published as a series of 1:5 million shaded relief maps. This series included three U.S. Geological Survey maps: I-1218-B, Shaded Relief Map of the Lunar Far Side, 1980; I-1326-A, Shaded Relief Map of the Lunar Polar Regions, 1981; and I-2276, Sheet 2 of 2, Shaded Relief Map of the Lunar Near Side, 1992. These data were digitized and mosaicked into a single digital file. Areas totaling approximately 500,000 km^2 near the south pole were not visible in any pre-Clementine images and are blank on the published map. The digitized relief base was revised to show features in this area, based on the Clementine mosaic and recent Earth-based radar images of the area. Errors still exist in the original interpretations of lunar morphology, therefore they exist in the warped shaded relief map base. These original interpretations were based on scanty data, ambiguities introduced by highly oblique solar incidence angles, and distortions created in generating orthophotos from oblique images. [9]

Topographic Data: The Clementine Laser altimeter points were used to interpolate a global topographic gridded digital terrain model for the lunar surface. Because the altimeter points were sparse near the poles and non-existent over the poles, the polar regions from this digital terrain model were clipped and only data between 75˚ S. and 75˚ N. were used in the final digital terrain model. To fill in the polar regions, topographic data were collected photogrammetrically from Clementine images.

For the photogrammetric project, horizontal control was established by selecting some of the match points that were used in building the Clementine global mosaic. These points provided estimates for latitude and longitude values and no estimate for elevation values. Vertical control was established by using the global topographic gridded digital terrain model developed from the Clementine laser altimeter points to estimate elevation values for the Clementine match points. Clementine match points were selected to tie two images together in order to build the Clementine global mosaic; for the photogrammetric project match points were transferred to all images that contained the point. Additional points were selected to have four well-distributed points per image, when possible. Analytical areotriangulation, a weighted least squares process, is used to solve for all the parameters of the photogrammetric project, which are: image sensor position and angles; latitude, longitude, and elevation of match points; and image coordinates of match points. Adjusting the weight assigned to a parameter determines whether values with high weight are held to the original estimate or values with low weight are allowed to float and a new value determined for the parameter. For this project, the image sensor angles are being determined, so they are given a low weight. The latitude and longitude values of Clementine match points are given a high weight so the solution holds to the Clementine global mosaic horizontal coordinates. Weights for the elevation values are varied depending on the horizontal distance to a Clementine laser altimeter point: match points within 2000 m of a Clementine laser altimeter point are given a high weight; match points between

2000 m and 5000 m from a Clementine laser altimeter point are given a medium weight; and match points greater than 5000 m from a Clementine laser altimeter point are given a low weight. This weighting procedure allows the vertical control to be bridged between areas on known vertical control, the outer part of the circle, and the areas void of control, the inner part of the circle over the poles.

The Clementine mission collected both oblique and vertical images over the polar regions; these images form stereo pairs that can be used photogrammetrically to collect topographic data. Over the south pole region (90° S. - 63° S. latitude) topographic data were collected from 667 stereo models. In the north pole region (90° N. - 64° N. latitude) there were 640 stereo models. Topographic data were collected within each stereo model with a post spacing of 1 km in the x and y direction. This resulted in 1,724,872 points being collected in the south pole region and 1,437,368 points being collected in the north pole region. On average, over the area that data were collected, the Clementine laser altimeter collected an elevation value for every 514 km^2; and the photogrammetric data collected an elevation value for every 1.2 km^2 in the south pole and every 1.3 km^2 in the north pole. The photogrammetric data were merged and vertically transformed to align with the Clementine laser altimeter data to form the final digital terrain model. [7]

Merging the topographic data required an iterative process to reduce the error between the photogrammetric data and the topographic data derived from the Clementine laser altimeter data. At first, the photogrammetric topographic data exhibited a systematic stair-step error, in that stereo models closer to the poles had a systematic bias to be higher than stereo models farther from the poles. When this bias was removed, the resulting digital terrain model had a bowl shape appearance with a low spot near the pole. Each stereo model was detilted to remove the bowl shape: for stereo models in the south pole area this was 1 km per degree and for stereo models in the north pole area this was 800 m per degree. To fit the stereo models to the Clementine laser altimeter data an initial set of stereo models that overlaid the Clementine laser altimeter data were adjusted to vertically align with the Clementine laser altimeter data. Then stereo models that overlaid the stereo models that were adjusted in the previous step were adjusted, and this process continued until all stereo models were adjusted to vertically align.

In analyzing the photogrammetric data for the north pole region, there are 1,189,935 points (83% of the data) that occur on two or more stereo models. For 90% of those points, the standard deviation in elevation is between 24 and 409 m, with a mean of 184 m. In the south pole region, there are 1,262,349 points (73% of the data) that occur on two or more stereo models. For 90% of those points, the standard deviation in elevation is between 13 and 395 m, with a mean of 160 m.

There are 1,276 Clementine laser altimeter points that are in the north pole region where photogrammetric topographic data were collected. Comparing the photogrammetric topographic data with the Clementine laser altimeter points shows that for the north pole region the topographic data is an average of 46 m higher than the Clementine laser altimeter points; with a standard deviation of 719 m. In the south pole region, there are 1,379 Clementine laser altimeter points that are in the area where photogrammetric topographic data were collected. For the south pole region the topographic data is an average of 163 m lower than the Clementine laser altimeter points; with a standard deviation of 1005 m.

The merged topographic data were color-coded and combined with the shaded relief data. There are areas where no topographic data were collected, those areas were not color-coded and the shaded relief image is shown as a grayscale image.

Nomenclature: The number, size and placement of text annotations were chosen to provide a general orientation of prominent features on a 1:10,000,000 scale map. Features are labeled with names approved by the International Astronomical Union (for a complete list of lunar nomenclature, see http://planetarynames.wr.usgs.gov).

Ordering Information: Maps produced by the U.S. Geological Survey may be ordered and purchased from commercial map dealers and certain government sites. The web site http://wwwflag.wr.usgs.gov/USGSFlag/Space/GEOMAP/MapInfo.html contains information about ordering maps. A web site that provides information about planetary geological maps is located at http://wwwflag.wr.usgs.gov/USGSFlag/Space/GEOMAP/PGM_home.html .

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