PLANETARY GEODESY AND CARTOGRAPHY AT THE USGS, FLAGSTAFF: MOON, MARS, VENUS, AND BEYOND

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Abstract

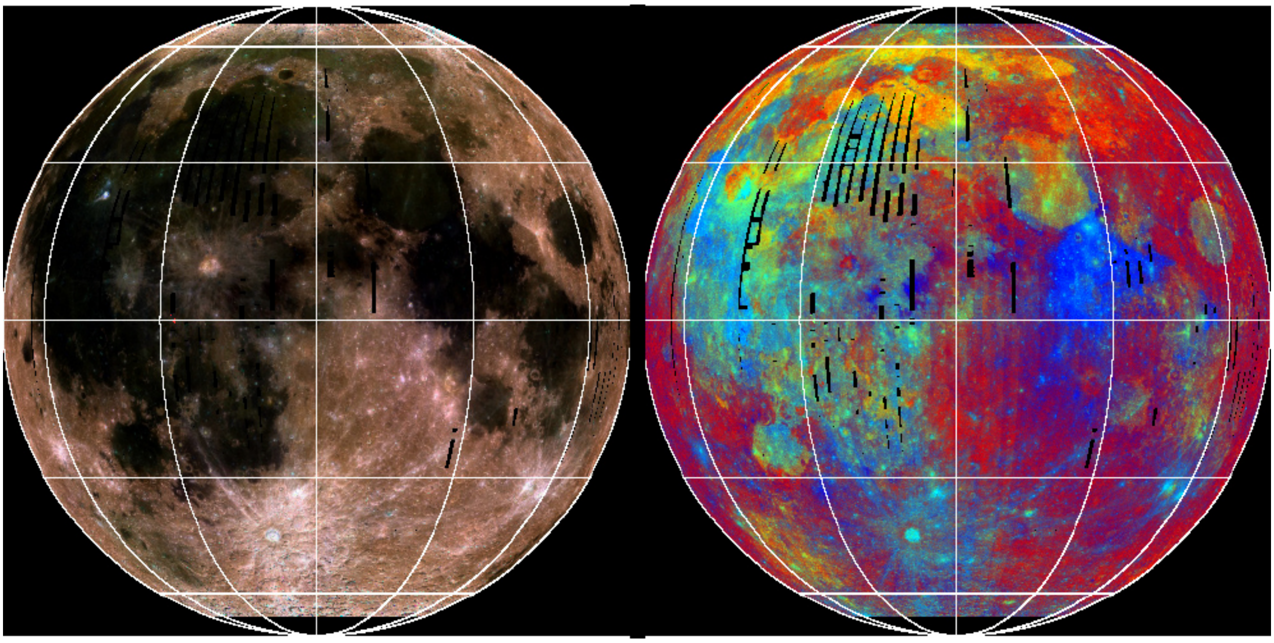
In this paper we present a collection of visual examples of data from recent and ongoing USGS mapping projects in support of the NASA program of planetary exploration.

An important theme of our work is the synergistic use of a variety of geodetic, cartographic, and photogrammetric software packages. The USGS digital cartographic software system ISIS provides most of the processing capability needed for planimetric mapping tasks such as our revision of the global digital image mosaic of Mars (MDIM). The geodetic control network on which this mosaic is based was produced at RAND with planetary bundle-block adjustment software that was developed there and that has recently been transferred to the USGS where we are also using it to compute a revised control network of Io from Voyager and Galileo images. The revised MDIM compiled in 2000 is substantially improved over the version produced from the same ~4500 Viking Orbiter images in 1991, both in geodetic accuracy and in radiometric/cosmetic quality. Maps of the Galilean satellites of Jupiter have also been improved geodetically and cosmetically as we have added Galileo images to the control networks and digital mosaics.

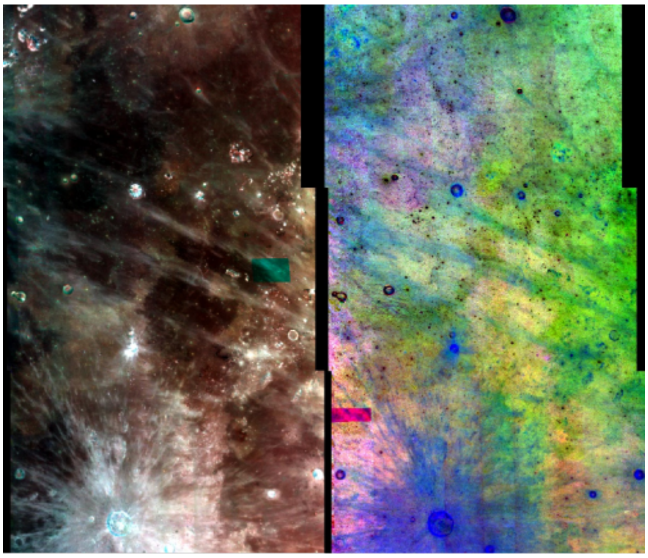
Stereotopographic mapping of the Moon, Mars, Venus, and the asteroid Eros requires ISIS for data ingestion and calibration steps, along with the commercial photogrammetric software SOCET SET® for "photogrammetric" steps such as adjustment of control and topographic model extraction and editing. Novel procedures must frequently be developed to deal with problems of planetary datasets such as the need to use large numbers of small images, nonuniform image coverage, poor image overlap, and lack of true ground control. Some sensors, such as the Magellan Synthetic Aperture Radar (SAR) and Mars Global Surveyor Mars Orbiter Camera (MOC), also require the development of specialized sensor model software.

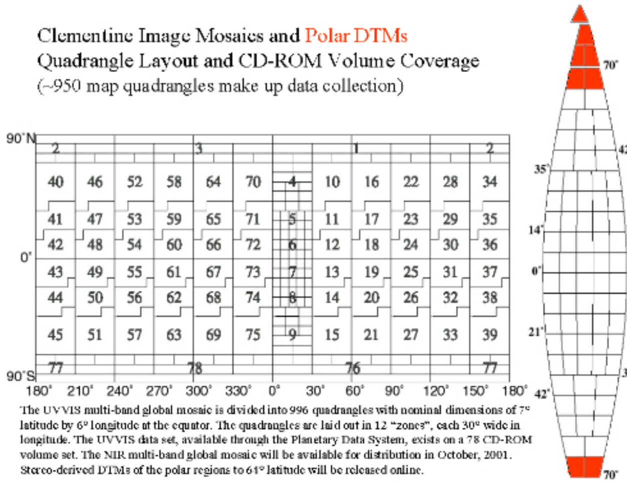
A second important theme is the complementarity between photogrammetric techniques and the laser altimeter systems coming into increasing use on planetary spacecraft. Stereoanalysis of Clementine images of the Moon has been used to fill in major gaps in the altimeter dataset at high latitudes, but the stereo data must be tied to the altimetry where the datasets overlap. For Mars and Eros, our stereomapping provides spatial sampling of topography finer than that achieved by altimetry, but use of the altimetry data for vertical control is essential to improve the absolute accuracy of photogrammetric topographic models. The dense spatial sampling of the Mars Orbiter Laser Altimeter (MOLA) dataset makes it useful as a source of horizontal control as well: features in images can easily be recognized in the altimetry and can be assigned coordinates with such small uncertainties that they function effectively as ground control points in the photogrammetric bundle-block adjustment. Such MOLA-derived ground points will be used to further improve the Viking Orbiter based control network and MDIM late in 2001 and will be incorporated into a subsequent network and mosaic based on global stereo imagery from MOC.

Moon

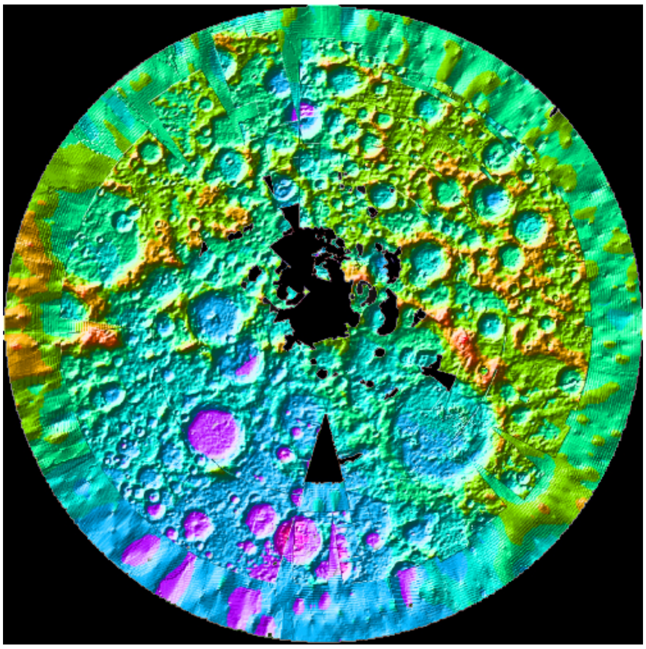


Left: Color mosaic of the lunar front side using 415nm (blue), 750nm(green), and 950nm (red) spectral filters from the UVVIS Imaging. Right: False color composite of ratioed image using 415/750 nm (blue), 750/950 nm (green), and 750/415 (red). Ratio composites cancel the albedo component and enhance the color signature differences due to age and mineralogy. Blue to red tones show overall color differences in the ultraviolet to near-infrared, indicating age differences in the highlands but titanium abundance in the maria. Yellow and orange colors indicate a greater abundance of iron and titanium-rich materials. The full resolution global image has approximately 110,000 pixels in longitude and 55,000 pixels in latitude.

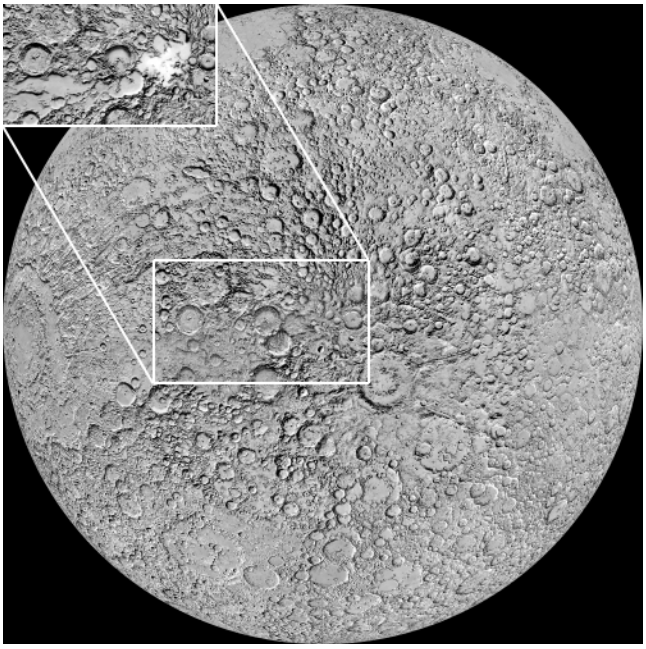




Kepler Crater (0°–7°N, 318°–330°W). Far left: color composite with 1100nm (blue), 1500nm (green), 2690nm (red). Left: color ratio composite 1100/1500 (blue), 2000/1500 (green), and 2000/1500 (red). Cartographic processing on Clementine NIR dataset to be completed in October, 2001.

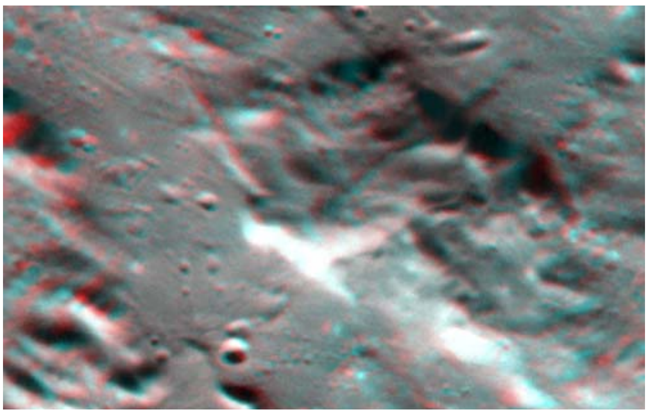


Color-coded shaded relief map of the south polar region of the Moon (64°–90°S). Most data shown were derived from stereoanalysis of Clementine images; low resolution data around edges are from Clementine laser altimeter. A systematic slope of 1 km per degree of latitude was removed from the stereo elevations to give agreement with altimetry and level out crater floors. This systematic error could not be removed by bundle-block adjustment (for which altimetric constraints were available only around the edges of the map) and its cause has not been determined. Polar DTMs will be distributed online once the north polar region is completed in mid- 2001.

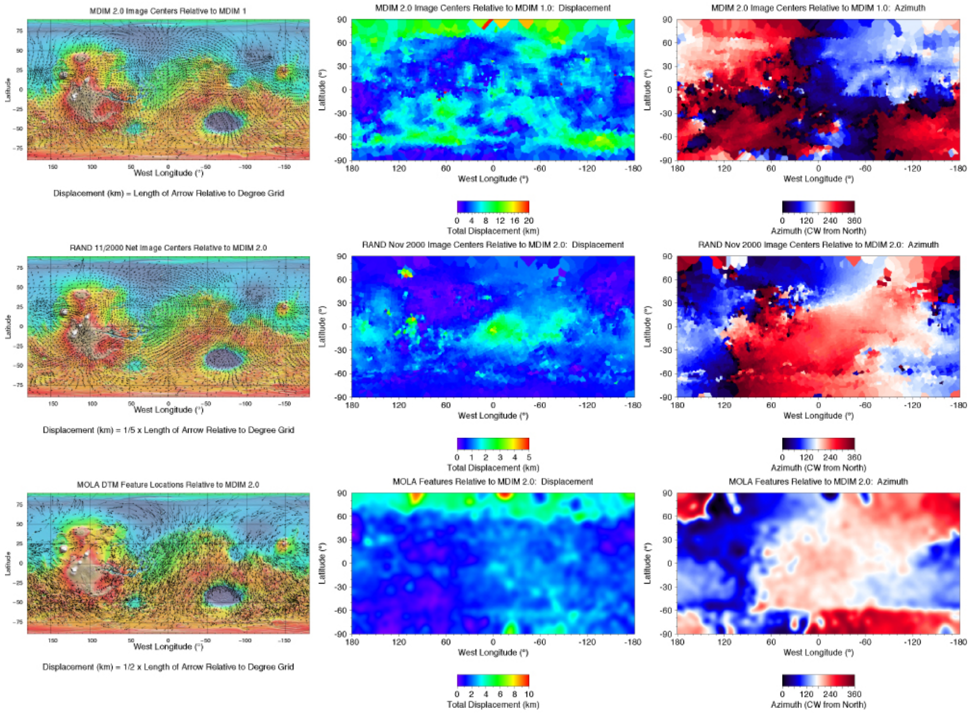


Revised airbrush shaded relief map of the southern hemisphere of the Moon in Stereographic projection. Existing airbrush maps of the entire Moon have been digitized and warped to conform to the Clementine control network, and features in the previously unseen 1.3% of the Moon near the south pole (inset shows blanks in existing map) have been added based on Clementine images. The revised maps will be printed with a topographic overlay at a scale of 1:10,000,000.

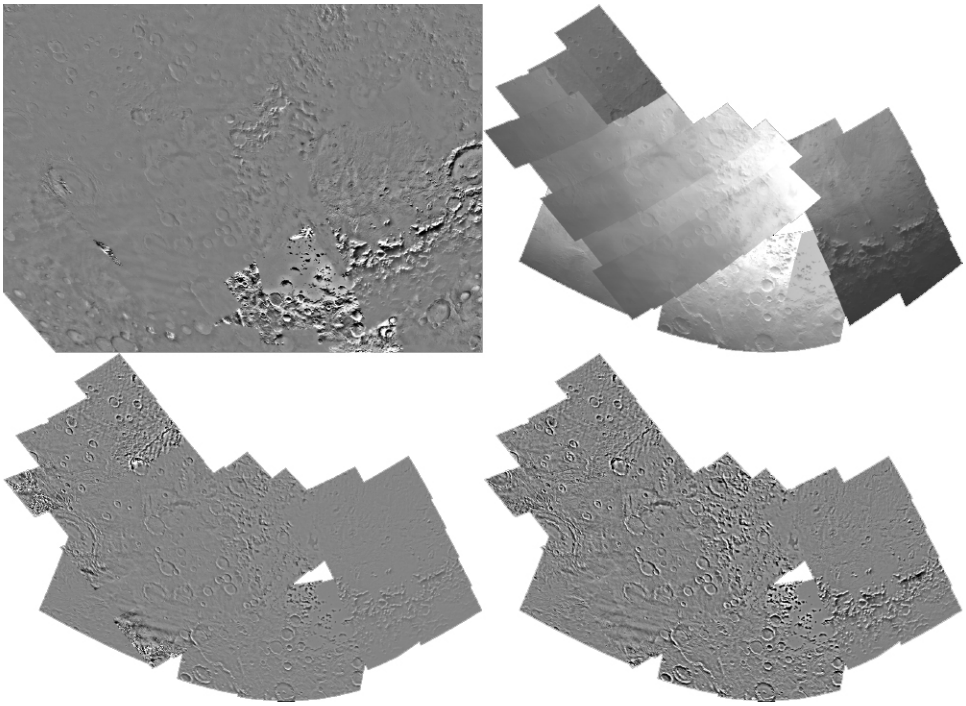
Stereoanaglyph created from a portion of two overlapping Lunar Orbiter (LO) 4 high-resolution frames. Scene is just south of Archimedes, and is about 80 km wide. We have completed a pilot project demonstrating the ability to digitize and digitally mosaic LO framelets into complete frames. Absence of "venetian blind" artifacts in apparent elevation in this stereo view confirms the subpixel geometric accuracy achieved by basing distortion corrections on the preprinted reseau pattern on the LO film. Geometrically accurate, full-resolution digital copies of the LO frames will open up new possibilities in lunar cartography. Approximately 550 LO 4 and 5 frames giving global coverage will be digitized and archived in 2002.



Mars

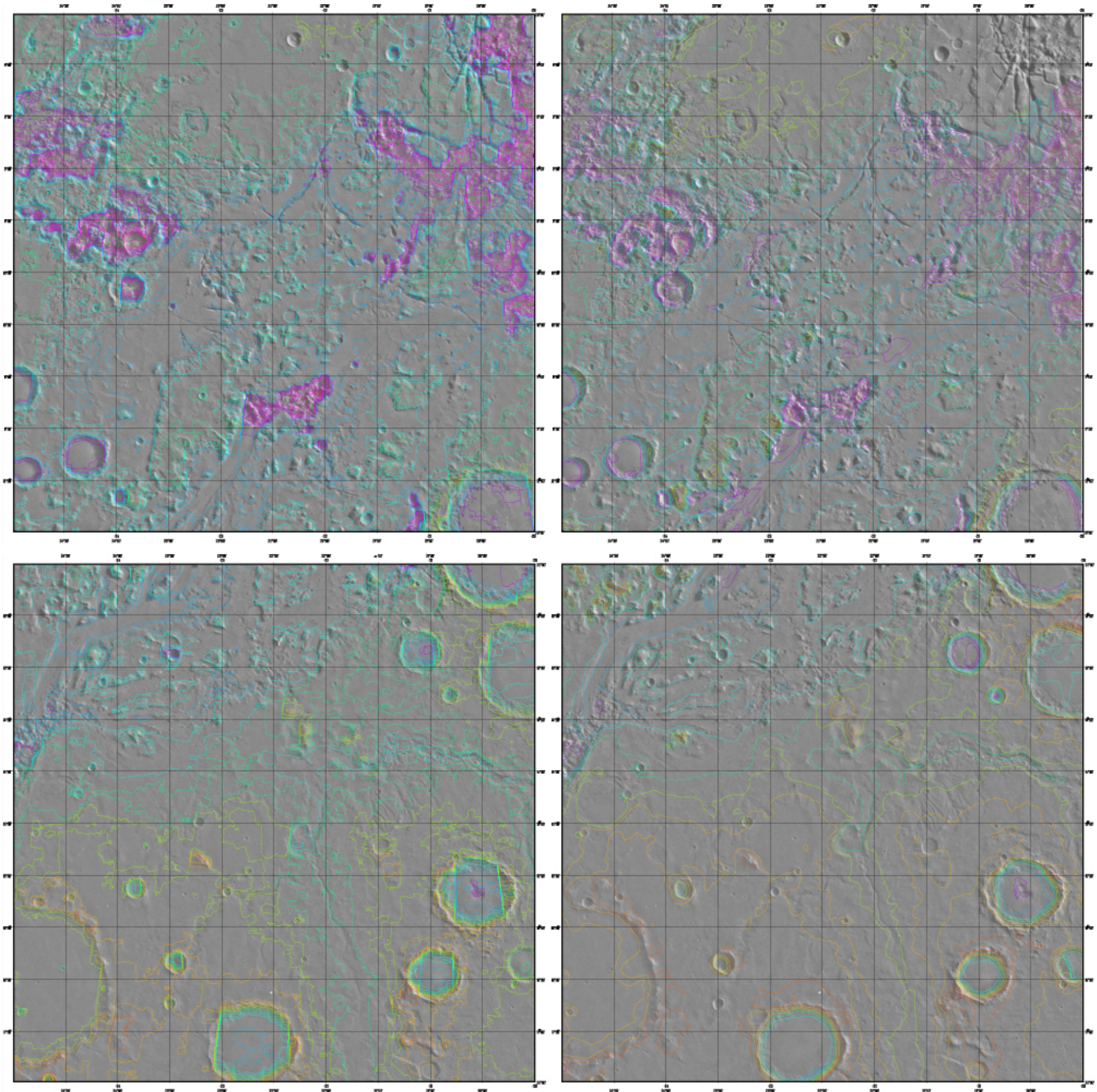


Revision of the global image mosaic of Mars (MDIM), originally released on PDS CDs in 1991, is a major activity at present. The poor positional accuracy of the original mosaic is the primary motivation; the plots above quantify the progress in improving this accuracy from ≥10-km absolute errors toward ~100-m errors. The first revised mosaic was completed in 2000 and is now available online. Top row of plots shows the change in location of the ~4500 images in the mosaic from 1991 MDIM 1.0 to 2000 MDIM 2.0, based on incorporation of MDIM image set into RAND global control network. Middle row shows changes as additional height constraints from MOLA were applied to RAND control points. Bottom row shows displacement vectors measured from MDIM 2.0 to MOLA global dataset, which has ~100-m absolute accuracy. MDIM 2.1 is in production, based on incorporation of horizontal control from MOLA into RAND network (now maintained by USGS) and will be distributed on PDS CD or DVD volumes in late 2001. Note that scales of plots differ and in each case the mean longitude shift has been removed to clarify regional displacements.



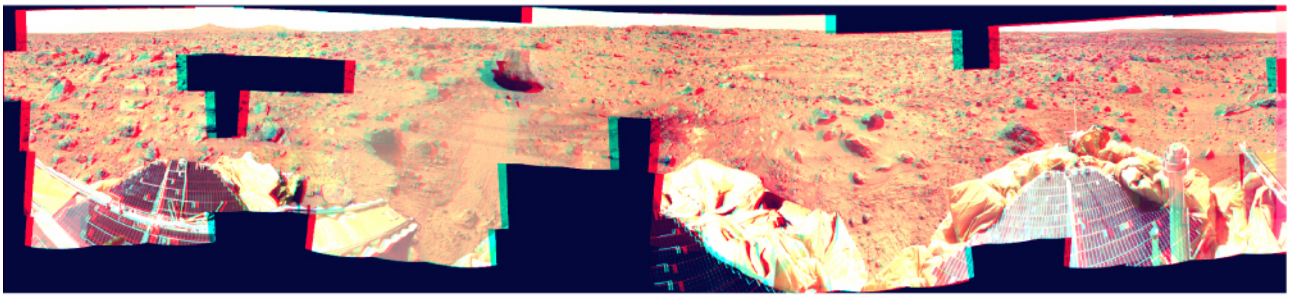
Revision of the MDIM also affords the opportunity to improve its cosmetic appearance. At upper left is part of MDIM 1.0 centered near 50°S, 60°W, showing some of the worst contrast/brightness mismatches in the original mosaic. Photometric normalization was extremely crude and based on a single estimate of atmospheric optical depth for all images. Remaining quadrants show mosaic of Viking data from several orbits in the same area. Upper left, with no photometric normalization, to show extreme variations of brightness and contrast due to differing incidence and phase angles. Lower left, with photometric model using separate optical depth estimate for each orbit but nearly isotropic scattering (used for MDIM 2.0) is improved but still shows a few areas of mismatched contrast. Lower right, extension of model to realistic, anisotropic scattering in atmosphere (as used for MDIM 2.1) results in uniform contrast except at the most extreme incidence angles at the lower right. Revision of global color mosaics using improved control and photometry is planned for 2002, followed by mosaicking of Mars Global Surveyor MOC global color image set.

The image base, grids, nomenclature, and documentation for these commercially available 12" (30.5 cm) diameter globes of Mars were recently prepared by the USGS. Globe at left uses a digital mosaic of Viking Orbiter 1 km/pixel color images merged with the 231 m/pixel MDIM 1.0 mosaic, which emphasizes topographic features. Globe at right uses a color-coded shaded relief map derived by the Mars Global Surveyor MOLA team from their global DTM.

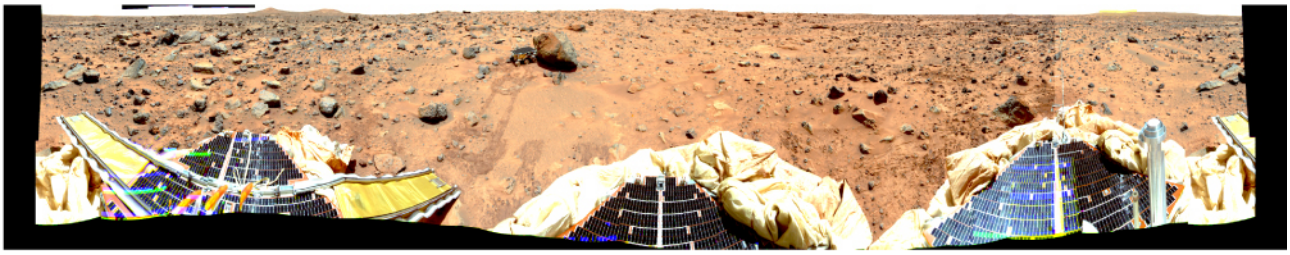


Examples of large-scale topographic mapping of Mars in support of NASA geologic mapping program. Shown are contour maps derived from DTMs gridded at 1 km/post for two adjacent 1:500,000-scale quadrangles. Quadrangle centered at 10°S, 22.5°W is shown in top maps and that centered at 15°S, 22.5°W at bottom; each map is 5° (~300 km) on a side. Contours at left are derived from MOLA altimetry and show substantial distortion of landforms caused by inadequate density of MOLA profiles to support this map scale. Contours at right are derived from stereoanalysis of Viking Orbiter images with resolutions 200–250 m/pixel, expected vertical precision (EP) 80–160 m. Part of top right map where stereo coverage is poor has been completed by deriving high-resolution DTM by photoclinometry, the first use of this technique in a published map. Availability of MOLA data to control vertical scale, regional tilt, and broad features of the DTM addresses the known model dependencies of photoclinometry that make it a poor source of cartographic data on its own. Contours are not spaced equally. Image base is MDIM 2.0 global mosaic.

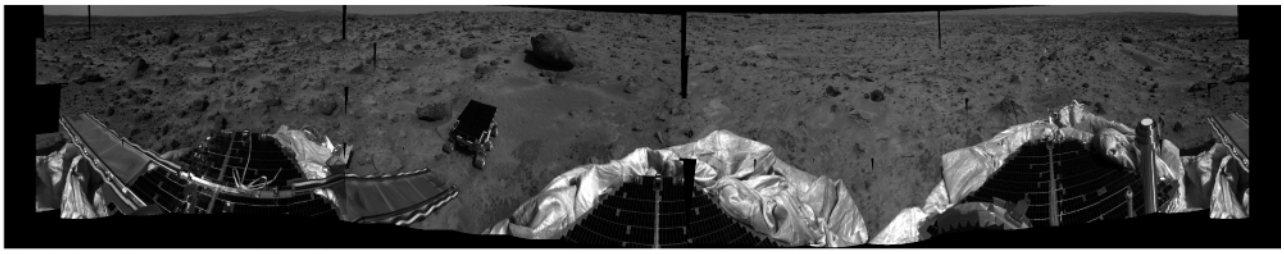
APEX Pancam Anaglyph



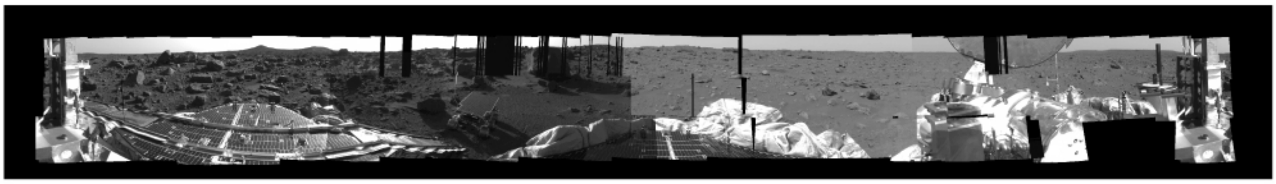
Super Pan Anaglyph (cosmetically enhanced)



Color Gallery Pan

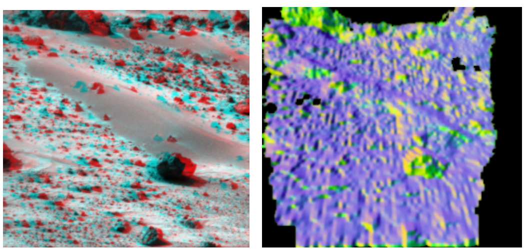


Right Eye Monster Pan (red)



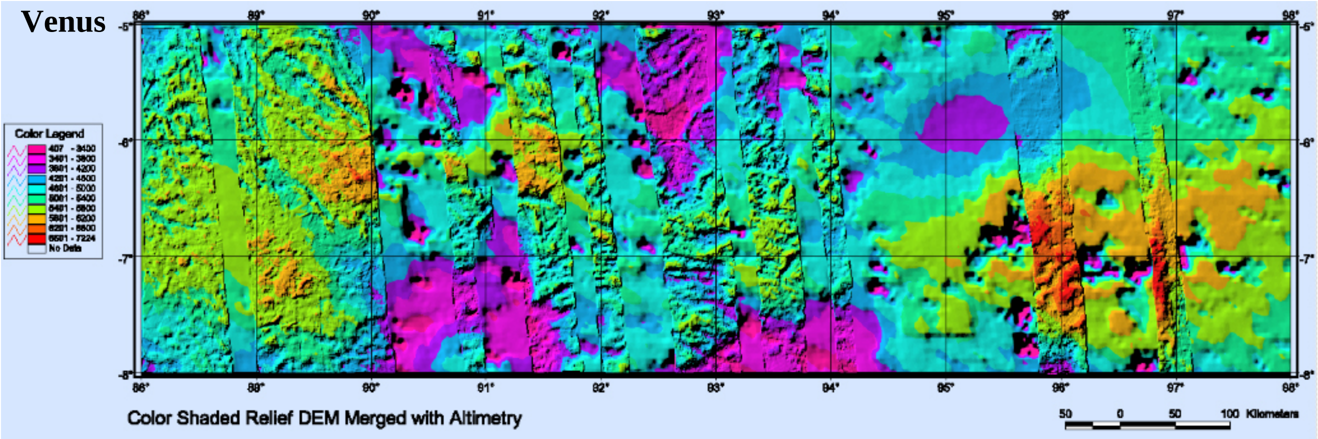
Left Eye Insurance Pan (red)

Panoramic mosaics of the Mars Pathfinder landing site constructed from IMP camera images. Mapping techniques developed during the mission in 1997 have been refined considerably and final products (including digital elevation/shape models as well as panoramic and planimetric mosaics) with subpixel geometric accuracy will be archived to the PDS in 2001. In addition to refining all image passpoint measurements to subpixel accuracy by area-based matching and repeatedly searching for blunders, it was necessary to include the orientation of the stereocameras within the IMP camera head as self-calibration parameters in the bundle-block adjustment. A similar approach was used to control the mosaic of APEX Pancam images seen at top, in preparation for Mars Exploration Rover Pancam cartography in 2004.

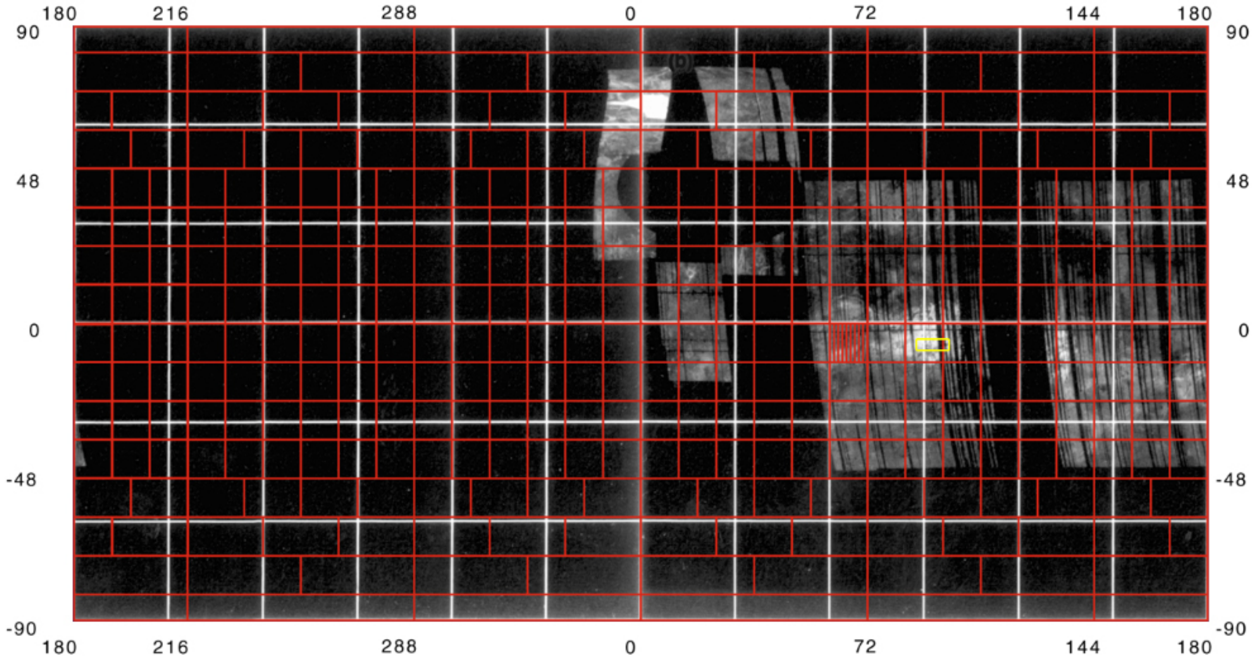


Example of quantitative application of Mars Pathfinder cartographic processing. Left: anaglyphic IMP image of Mermaid duneform. Right, pseudo-image portraying surface orientations as computed from stereo-derived digital shape model of the same scene. Components of normal vector to surface in the global X, Y, and Z directions correspond to red, green, and blue intensities (image has been smoothed and stretched to improve color discriminability). Photometric correction of the IMP color images based on surface normal maps like this is necessary to achieve accurate spectroscopy because of the differing colors of sunlight and martian skylight.

Venus

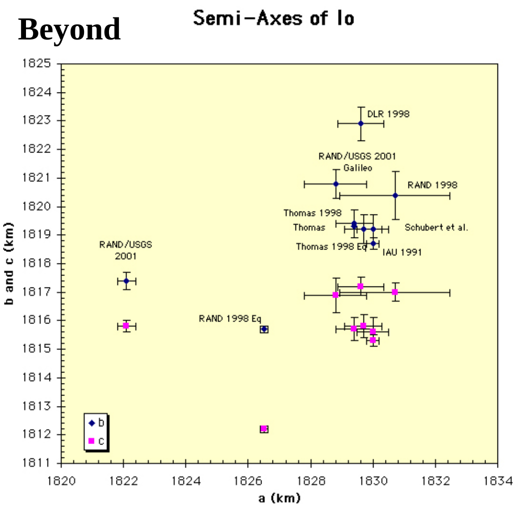


Color-coded shaded relief map of part of Ovda Regio, Venus (8°–5°S, 88°–98°E). Digital elevation model (DEM) generated by us from stereoanalysis of Magellan radar (SAR) images has been overlaid on Magellan altimetry data, which is visible between strips of available SAR coverage. Superior resolution of stereo DEM (collected at 1 km/post) is apparent. Good vertical agreement between datasets results from bundle-block adjustment of images with elevation constraints from altimetry. In some places (e.g., 7°S, 95°–97°E) altimetry contains artifacts with apparent elevation ~3 km below surround. Artifacts result from contrast between radar-dark minerals at elevations above 6000 m and brighter, lower surround. Distribution of dark materials in SAR images thus provides a check on the stereo DEM results in this particular region.

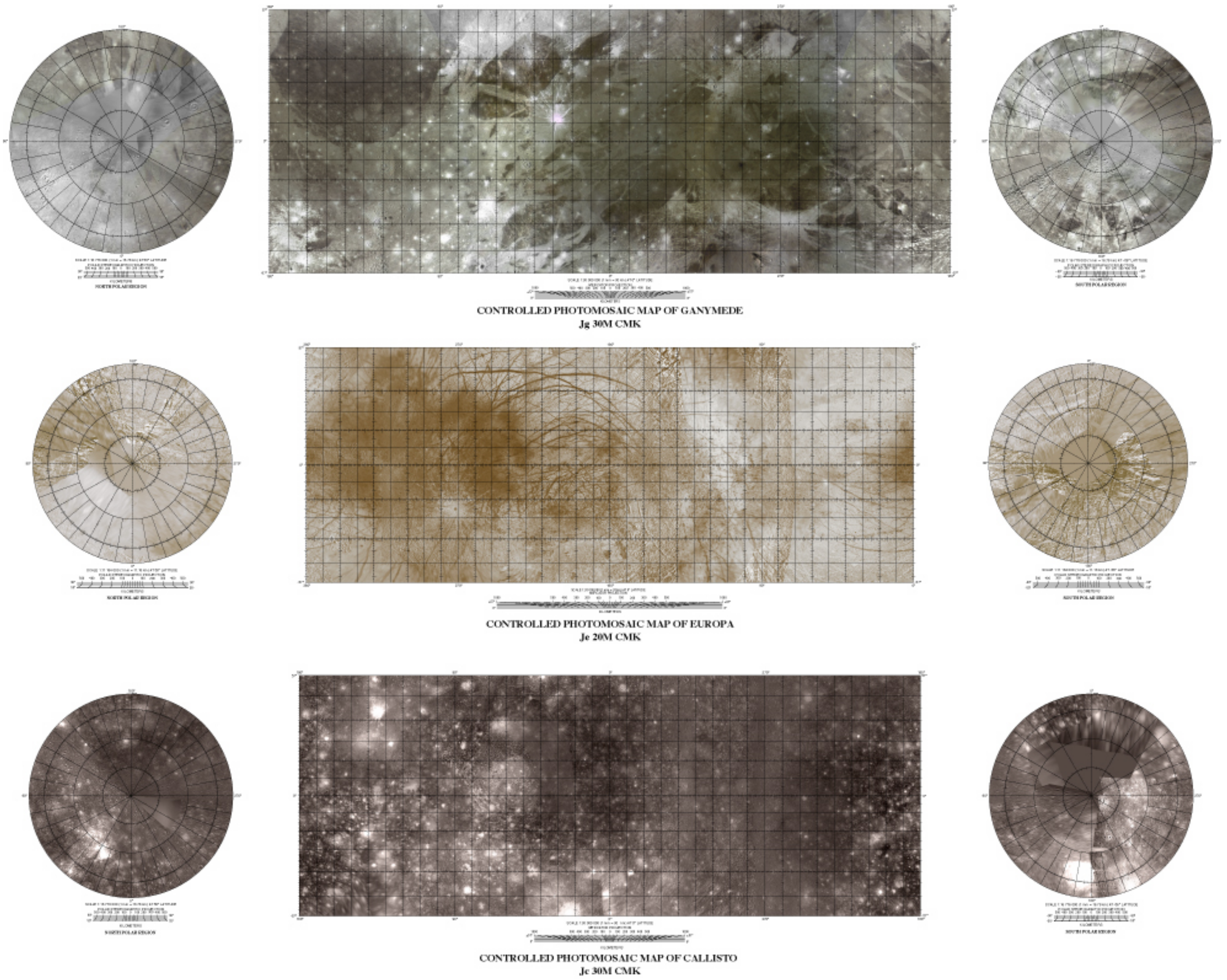


Map showing Magellan stereo image coverage, totaling about 17% of Venus. Reduced look-angle coverage from global mapping Cycle 3 is shown as gray image base; nominal look-angle coverage from earlier Cycles, needed to complete the stereopair, covers essentially the whole area. Sufficient coverage exists to support stereotopographic mapping of about 80 out of 170 USGS 1:1.5M global mosaic (FMAP) quadrangles, shown in red. Area for which topographic map is shown above is outlined in yellow; red hatching indicates Joliot-Curie FMAP quadrangle, mapped in 2000. Topomapping of additional quadrangles adjacent to Joliot-Curie will continue, with DEMs distributed online as they become available.

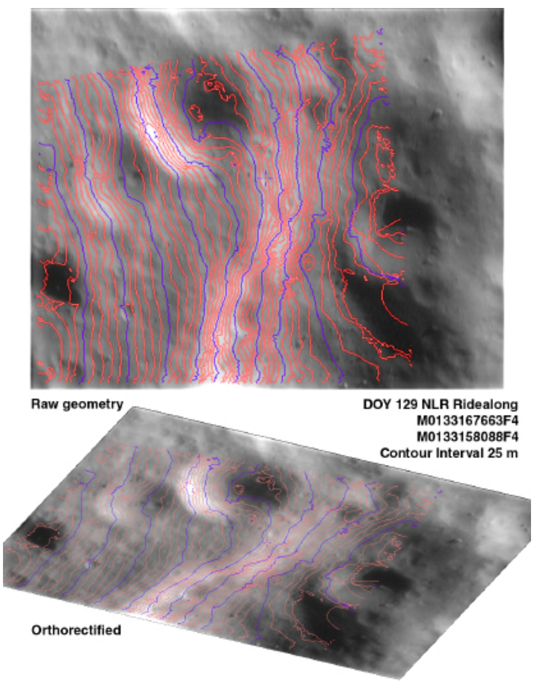
Beyond

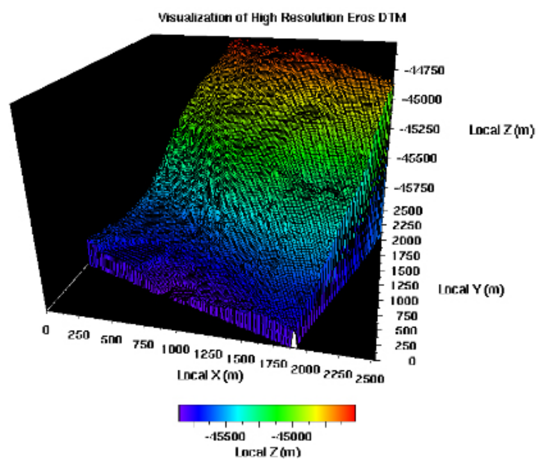


Galileo SSI image data have reactivated geodesy/cartography of the major satellites of Jupiter. Achieving a satisfactory geodetic control network on which to base maps of Io is particularly challenging, in part because temporal changes, color contrasts, and contrast reversals of features with phase angle make image matching difficult. Coverage of the Jupiter-facing hemisphere is also of low resolution and poor quality. In consequence, dynamical solutions and different control calculations give different dimensions for the best-fit triaxial ellipsoid, as seen at left. Solutions involving Voyager images have consistently been significantly smaller than those based on SSI alone. We have traced this discrepancy to poor image measurements on Voyager images, mainly of the Jupiter-facing hemisphere, and are revising those measurements. When a joint Voyager/Galileo control net is completed, color and monochrome image mosaics will be prepared, including separate versions showing changes between the Voyager and Galileo eras.



Recently completed global image mosaics of the icy Galilean satellites of Jupiter. Mercator and Polar Stereographic maps for each satellite will be printed on a single sheet at a scale of 1:15M at the equator; for this figure, a different scale has been used for each body and polar maps have been located to the sides. Ganymede mosaic is approximately natural color, derived from Galileo 3-band and Voyager 2-band image coverage, with single-band fill near the poles. Europa and Callisto mosaics are single-band, tinted to approximate visual appearance of the respective satellites.





Example of stereotopographic mapping of asteroid 433 Eros using images from the NEAR multispectral imager (MSI). Global control networks for Eros are being created by the MSI team and the NEAR navigation team, and an independent global shape model is being constructed by the Near Laser Rangefinder (NLR) team. USGS efforts focus on obtaining high-resolution DTMs by stereo and photoclinometric analysis of images to support scientific analysis of surface features. Example shown here is from 6 m/pixel images, with 25 m contour interval at left. Same area is shown in perspective view above. Individual DTMs like this in local coordinate systems can be rotated to and assembled in global coordinates by using techniques developed for Mars Pathfinder.

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